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ABSTRACT

This manual provides in-depth coverage of topics related to boiler operations. The assignments contain an objective, descriptive information, reference sources, procedures, and assignments. Sixteen units are provided and address topics such as: (1) steam engineering concepts; (2) boiler fittings; (3) feed-water, steam, and combustion accessories; (4) combustion; (5) boiler-water conditioning; (6) electrical components; (7) pumps; (8) turbines; (9) lubrication; (10) plant operation; (11) service and maintenance; and (12) license preparation. Several diagrams complement the activity units. Numerous engineering drawings are included. (ML)

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Department of Education
Division of Vocational Education
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STATIONARY ENGINEERING
SCIENCE MANUAL - 3

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Introduction

During this last year of your course in Stationary Engineering, you will notice that your science manual will go a little deeper into the theory of Stationary Engineering. The A.S.M.E. Code and the rules and regulation of the Mechanical Inspection Bureau will be stressed. A good operator should have a good understanding of *why* things work the way they do.

The Authors,

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Objectives: Be able to list the traits expected in a boiler operator and engineer.

Be able to apply these traits to specific situations involving boiler operation.

Information: The boiler operator and stationary engineer are responsible for the safe and efficient operation of the plant. State law requires that licensed personnel be on duty when boilers are firing; they must not leave their shift until they are properly relieved.

Trait No. 1, then, requires that a boiler operator or engineer be *dependable.* If this person fails to report, then the one on shift is stuck for another 8 hours.

Trait No. 2 requires you to be *sober* at all times. Boilers are dangerous and require good judgment for safe operation. Drugs and alcohol greatly affect a person's judgment of what is the proper thing to do.

Trait No. 3 requires *truthfulness* at all times. If your shift engineer or chief engineer questions you about any situation, the answers must be truthful. A lie could cause troubleshooting to take the wrong direction, leading to serious and expensive down time.

Trait No. 4 requires that you be *cool and calm* in any and all situations. The boiler operator or engineer who knows the equipment and the plant will know what to do in any emergency situation. A person who does not know will panic and be useless in emergencies.

Trait No. 5 requires that you be *diligent* in the performance of your duties. If a plant is allowed to run with little or no attempt to achieve or maintain high standards of efficiency, the plant will start to fall apart. If the company does not make money and if plant-operation costs get out of hand, the plant will be closed down and jobs will be lost.

Let's just look back at what we have been talking about:

Traits of a boiler operator and engineer

1. Dependable
2. Sober
3. Truthful
4. Cool and level-headed
5. Diligent

References: Rules and regulations — Mechanical Inspection Bureau.

Procedure: After studying the information and listed references, answer the following questions and be prepared to discuss each.

Assignment:

1. Can you explain why it is necessary to have a licensed operator on duty when boilers are firing?

2. Who can decide how far away a boiler operator or engineer can go from the boilers, and for how long?

3. Why must a boiler operator wait for a relief?

4. Can a plant engineer relieve a boiler operator or a watch engineer?

5. How would you handle this situation? You are a boiler operator in charge of your own shift in a plant that has two 250 hp boilers. Your relief operator shows up at 11:45 p.m. and is quite drunk.

   a. You have known this operator for 5 years and this has never happened before.

   b. You have known this operator for 6 months and this happens at least once a week.

Objective: Be able to describe what OSHA is and how it relates to plant safety.

Information: Plant safety has been talked about for years and years. The small problems have been handled fairly well. You can go into almost any plant and see signs that read "36 days with no lost-time accidents," etc. What hasn't been posted is "No lives lost due to job-related causes."

We still haven't been able to convince workers, unions, manufacturers, and the government that strong stands must be taken to protect the worker and the public. If a product or a process is harmful to the worker or the public in general, it should not be phased out in 5 or 10 years; it should be stopped immediately. We can't wait for tomorrow; tomorrow is too late.

OSHA has been handling the small problems, but it just doesn't seem to see or find the big problems. It will be your responsibility when you are out in industry to bring into the open anything that is harmful to the worker or public. Get the news media involved; there is always some young reporter who will work to make headlines. Don't sit back and say, "What can I do?" Make OSHA work! It's there to protect us all.

Reference: OSHA Manual

Procedure: Read the information, study the OSHA Manual, and then do the following assignment.

Assignment:

1. Starting Sunday and for the next 6 days, read through your daily paper. Cut out every article covering job-related accidents.
2. Cut out every article about pollution or other situations that are injurious to the public health.

Objective: Be able to define the terms *pressure, work,* and *power.*

Be able to solve problems involving pressure, work, and power.

Information: **Pressure** is defined as force per unit of area. The formula is:

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

Example 1: A force of 1000 pounds is applied to an area of 4 square inches. What is the pressure?

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}} = \frac{1000}{4} = 250 \text{ p.s.i.}$$

By rearranging the above formula, the area can be found when the force and pressure are known, and the force can be found if the pressure and area are known.

$$\text{Area} = \frac{\text{Force}}{\text{Pressure}} \qquad \text{Force} = \text{Pressure} \times \text{Area}$$

Work is defined as a force acting on a body and moving it through a distance. The formula is:

$$\text{Work} = \text{Force} \times \text{Distance}$$

Example 2: A force of 100 pounds is applied and moves an object 50 feet. How much work was done?

$$\text{Work} = \text{Force} \times \text{Distance}$$

$$\text{Work} = 100 \times 50 = 5{,}000 \text{ ft.-lbs.}$$

By rearranging the above formula, the force can be found if work and distance are known, and distance if work and force are known.

$$\text{Force} = \frac{\text{Work}}{\text{Distance}} \qquad \text{Distance} = \frac{\text{Work}}{\text{Force}}$$

Power is the rate of doing work. The formula is:

$$\text{Power} = \frac{\text{Work}}{\text{Time}} = \frac{\text{Force} \times \text{Distance}}{\text{Time}}$$

Example 3: An engine does 140,000 ft.-lbs. of work in 4 minutes. How much power was developed?

$$\text{Power} = \frac{\text{Work}}{\text{Time}} = \frac{140{,}000}{4} = 35{,}000 \text{ ft. lbs./min.}$$

Example 4: A force of 200 pounds is applied and moves an object 100 feet in 2 minutes. How much power was used?

$$\text{Power} = \frac{\text{Force} \times \text{Distance}}{\text{Time}}$$

$$\text{Power} = \frac{200 \times 100}{2} = 10{,}000 \text{ foot-pounds/min.}$$

References: *Steam Plant Operation*
Elementary Steam Power
Stationary Engineering Science Manual 2

Procedure: After having studied the above information and the listed references, answer the following questions and be prepared to discuss each.

Assignment:

1. What is pressure?
2. Define the term *work.*
3. Define the term *power.*
4. Find the force on a safety-valve disc that has an area of 6.25 square inches and is connected to a boiler with a pressure of 100 p.s.i.
5. Find the area of a flat surface that has a force of 1000 pounds acting on it and produces a pressure of 12 p.s.i.
6. What is the pressure on the top of a compressor piston if the force is 20,000 pounds and the area of the piston is 85 square inches?
7. How much work would be done when moving a 500-pound safe 20 feet?
8. A freight elevator does 50,000 foot-pounds of work while lifting a 3,000-pound load. How high did it lift the load?

Objectives: Be able to define the term *mechanical horsepower.*

Be able to solve simple problems involving mechanical horsepower.

Be able to define the term *boiler horsepower.*

Be able to solve simple problems involving boiler horsepower.

Information: Mechanical horsepower is defined as the power necessary to perform work at a rate of 33,000 foot-pounds per minute.

$$\text{Horsepower} = \frac{\text{Work}}{\text{Time} \times 33{,}000} = \frac{\text{Force} \times \text{Distance}}{\text{Time} \times 33{,}000}$$

Example 1: What is the horsepower developed by a machine that can do 140,000 foot-pounds of work in 4 minutes?

$$\text{Horsepower} = \frac{\text{Work}}{\text{Time} \times 33{,}000}$$

$$\text{hp} = \frac{140{,}000}{4 \times 33{,}000} = 1.06 \text{ hp}$$

Example 2: A pump discharges 1000 pounds of water per minute against a total head of 150 feet. How much water horsepower is developed?

$$\text{hp} = \frac{\text{Foot Pounds}}{\text{Time} \times 33{,}000}$$

$$\text{hp} = \frac{150 \times 1000}{1 \times 33{,}000} = 4.55 \text{ hp}$$

Both of these examples refer to mechanical horsepower and must not be confused with boiler horsepower. One boiler horsepower is defined as the evaporation of 34.5 pounds of water per hour from and at 212°F.

If 970.3 Btu per pound is the latent heat of vaporization of water at 212°F., it then follows that

$$1 \text{ Boiler horsepower} - 970.3 \times 34.5$$

$$1 \text{ Boiler hp} = 33475 \text{ Btu per hour}$$

Since steam boilers do not operate with steam-water temperatures of 212°F, a correction factor must be introduced. This is known as the factor of evaporation. When this factor is used, the developed boiler horsepower is found as follows –

$$\text{Developed boiler horsepower} = \frac{\text{Pounds of steam per hour} \times \text{Factor of evaporation}}{34.5}$$

As you may recall, the factor of evaporation formula is

$$\text{Factor of Evap.} = \frac{H_S - h_{FW}}{970.3}$$

Where: H_S is the enthalpy of saturated steam at the pressure on the boiler drum.

h_{FW} is the enthalpy of the feedwater as it enters the boiler drum.

Example 3: A boiler evaporates 10,000 pounds of steam per hour with a factor of evaporation of 1.24. Find the developed boiler horsepower.

$$\text{B hp} = \frac{W_S \times \text{F of E}}{34.5}$$

Where W_S represents the pounds of steam per hour.

$$\text{B hp} = \frac{10{,}000 \times 1.24}{34.5}$$

$$\text{B hp} = 359.42$$

Example 4: A boiler evaporates 30,000 pounds of steam per hour. The steam pressure is 130 psi and has a heat content of 1190.7 Btu per pound. The feedwater temperature is 210°F. Find the boiler horsepower.

$$\text{B hp} = \frac{W_S\,(H_S - h_{FW})}{33{,}475}$$

$$h_{FW} = 210 - 32 = 178$$

$$\text{B hp} = \frac{30{,}000\,(1190.7 - 178)}{33{,}475}$$

$$\text{B hp} = 907.6$$

From examples #3 and #4, it can be readily seen that the B hp can be determined. But in each case, the method used depends on the information given.

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Procedure: After reading the information and studying the references, do the following assignment and be prepared to discuss it.

Assignment:

1. Define the term *mechanical horsepower.*
2. A machine can do 99,000 foot-pounds of work in 3 minutes. Find its horsepower.
3. What horsepower is needed to lift a 10-ton machine 100 feet in 2 minutes?
4. A pump delivers 50 cubic feet of water per minute from a depth of 200 feet. Water weighs 62.5 pounds per cubic foot. Calculate the horsepower.
5. A feedwater pump delivers 30,000 pounds of water per hour at a pressure of 300 psi. Calculate the water horsepower.
6. Define the term *boiler horsepower.*
7. How many Btu's are equivalent to one boiler horsepower?
8. Define the term *factor of evaporation.*
9. A boiler evaporates 30,000 pounds of steam per hour and has a factor of evaporation of 1.09. Find the developed boiler horsepower.
10. A boiler produces 80,000 pounds of steam per hour at 250 psi. The steam has a heat content of 1200 Btu's per pound. The feedwater entering the boiler is 210°F. Find the developed boiler horsepower.

Objectives: Be able to explain the basic properties of heat:

a. Definition of heat
b. Basic terms
c. Measurement of temperature and heat
d. Transmission of heat
e. Temperature-scale conversions
f. Mechanical equivalent of heat

Information: The following facts must be remembered if we are to have a better understanding of heat.

1. **Heat** is a form of energy due to the motion of the molecules of a substance.

2. **Latent heat** will change the state of a substance but not its temperature.

3. **Sensible heat** will change the temperature of a substance but not its state.

4. **Latent heat of fusion** is the number of Btu's necessary to change one pound of a substance from a solid to a liquid at a constant temperature.

5. **Latent heat of vaporization** is the number of Btu's necessary to change one pound of a substance from a liquid to a gas at a constant temperature.

6. **Temperature** is the degree or the intensity of heat. It can be measured with a thermometer or instrument, in degrees (Fahrenheit or Celsius).

7. **Quantity of heat** is the *amount* of heat, measured in Btu's from a given base. (One Btu is the amount of heat necessary to change the temperature of one pound of water one degree F.)

8. **Transmission of heat** occurs in three ways: by **conduction** (direct contact of molecule to molecule), **convection** (involves currents in a fluid), **radiation** (a wave motion, requiring no substance or material between the source of heat and the thing heated).

9. **Temperature conversions.** When changing from degrees Fahrenheit to degrees Celsius, use the following formula:

$$^\circ C = \frac{^\circ F - 32}{1.8}$$

When changing from degrees Celsius to degrees Fahrenheit, use the following formula:

$$^\circ F = 1.8 \times {}^\circ C + 32$$

And when changing to degrees Rankine:

$$^\circ R = {}^\circ F + 460$$

10. **Mechanical equivalent of heat.** There are 778 foot-pounds in one British thermal unit.

Reference: *Elementary Steam Power Engineering*
Steam Plant Operation

Procedure: After studying the information and references, do the following assignment.

Assignment:

1. What is heat?

2. Define *British thermal unit.*

3. Define *latent heat* and *sensible heat.*

4. Explain the difference between temperature and quantity of heat.

5. Define *mechanical equivalent of heat.*

6. a. In what ways can heat be transmitted?
   b. Explain each way.

7. Define *latent heat of fusion* and *latent heat of vaporization.*

8. Convert the following temperatures as indicated.
   a. 68 degrees F. to degrees C.
   b. —40 degrees F. to degrees C.
   c. 140 degrees C. to degrees F.
   d. 20 degrees C. to degrees F.
   e. 32 degrees F. to degrees C.

9. How many Btu's are there in a mechanical horsepower?

10. How many Btu's are there in a boiler horsepower?

Objectives: Be able to solve problems using Charles' and Boyle's gas laws.

Be able to solve problems using the general gas law.

Information: The following is a list of basic facts that you should recall:

1. Charles' first law is for a constant pressure on a gas:

   At a constant pressure, the volume of a gas will vary directly with its temperature.

   $$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

2. Charles' second law is for a constant volume of a gas:

   At a constant volume, the pressure of a gas will vary directly with its temperature.

   $$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

3. Boyle's law for a constant temperature on a gas is:

   At a constant temperature, the volume of a gas will vary inversely with the pressure.

   $$P_1V_1 = P_2V_2$$

4. Combining Charles' and Boyle's laws gives the following formula:

   $$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

The units for the above equations will be:

1. Volume in cubic feet.
2. Temperature in degrees rankine.
3. Pressure in pounds per square inch absolute.

Example 1: What would be the volume of 10 cubic feet of gas at 90°F if it was heated to 200°F?

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \qquad V_2 = \frac{V_1 T_2}{T_1}$$

$$V_1 = 10 \text{ cu. ft.} \qquad V_2 = ?$$

$$T_1 = (90 + 460)^\circ R \qquad T_2 = (200 + 460)^\circ R$$

$$V_2 = \frac{10 \times 660}{550}$$

$$V_2 = 12 \text{ cu. ft.}$$

Example 2: Find the pressure on a gas tank that has been heated from an initial temperature of 90°F. at 100 psia to 200°F.

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \qquad P_2 = \frac{P_1 T_2}{T_1}$$

$$P_1 = 100 \text{ psia} \qquad P_2 = ?$$

$$T_1 = (90 + 460)^\circ R \qquad T_2 = (200 + 460)^\circ R$$

$$P_2 = \frac{100 \times 660}{550}$$

$$P_2 = 120 \text{ p.s.i.a.}$$

Example 3: If one cubic foot of air is expanded at constant temperature to two cubic feet and the initial pressure was 100 psia, what is the final pressure?

$$V_1 = 2 \text{ cu. ft.} \qquad V_2 = 2 \text{ cu. ft.}$$

$$P_1 = 100 \text{ psia} \qquad P_2 = ?$$

$$P_1 V_1 = P_2 V_2$$

$$P_2 = \frac{P_1 V_1}{V_2}$$

$$P_2 = \frac{100 \times 1}{2}$$

$$P_2 = 50 \text{ p.s.i.a.}$$

Example 4: From the following data, what would be the final gas volume:

P_1 = 15 psia P_2 = 30 psia
V_1 = 1 cu. ft. V_2 = ?
T_1 = 70° F. T_2 = 600° F.

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$V_2 = \frac{P_1V_1T_2}{T_1P_2}$$

$$V_2 = \frac{15 \times 1 \times (600 + 460)}{(70 + 460) \times 30}$$

$$V_2 = 1 \text{ cu. ft.}$$

The General Gas Law derived from combining Charles' and Boyle's laws can be expanded to form a new equation, which has been found to be very useful in the solution of gas problems. It is as follows:

$$PV = MRT$$

P – pressure in pounds per square foot absolute
V – volume in cubic feet
M – the mass in pounds
R – gas constant (Found in tables)
T – temperature in degrees Rankine

Example 5: A compression tank has a volume of 10 cubic feet and is full of air with a temperature of 200°F. The pressure on the tank is 85 psi. How much does the air in the tank weight?

$PV = MRT$ $M = \frac{PV}{RT}$

$P = (85 + 15)144$ psfa $R = 53.3$ (from tables)
$V = 10$ cu. ft. $T = (200 + 460)°R$
$M = ?$

$$M = \frac{14{,}400 \times 10}{53.3 \times 660}$$

$$M = 4.09 \text{ lbs.}$$

Example 6: What is the temperature of an air tank when it contains 6 pounds of air under a pressure of 135 psi and with a volume of 9 cu. ft?

$$P = (135 + 15)144 \text{ psfa} \qquad R = 53.3$$
$$V = 9 \text{ cu. ft.} \qquad M = 6 \text{ pounds}$$

$$PV = MRT$$

$$T = \frac{PV}{MR}$$

$$T = \frac{150 \times 144 \times 9}{6 \times 53.3}$$

$$T = 607.9°R \text{ or } 147.9°F.$$

References: *Applied Physics*
Elementary Steam Power Engineering

Procedure: After studying the information and the listed references, complete the following assignment and be prepared to discuss each problem in class.

Assignment:

1. Explain Charles' first and second laws for gases.
2. Explain Boyle's gas law for constant temperature.
3. What is the equation that combines Charles' and Boyle's laws?
4. What are the other two equations that are derived from Charles' and Boyle's laws?
5. A gas with an initial temperature of 60°F. and a volume of 5 cu. ft. is heated at a constant pressure to 580°F. What is its final volume?
6. A gas has an initial temperature of 80°F. and a pressure of 30 psi. If the gas is heated until the final pressure is 50 psi, what is the final temperature in °F., if the volume is kept constant?
7. Five pounds of air are expanded at a constant temperature from an initial volume of 5 cu. ft. to a final volume of 10 cu. ft. If the initial pressure of the air is 20 psia, what is the final pressure?
8. Four cubic feet of gas are allowed to expand at a constant temperature from an initial pressure of 8 psia to a final pressure of 2 psia. What is the final volume of the gas?

9. Solve for the unknown values:

P_1	V_1	T_1	P_2	V_2	T_2
100	5	600	250	10	?
50	10	650	150	?	850
30	25	700	?	15	1400

Note. All the above values are in absolute units – psia, cu. ft., °R.

10. What is the weight of oxygen in a 5 cubic foot cylinder if its pressure is 2200 psi and it has a temperature of 85°F? (Oxygen has a gas constant of 43.8.)

Enthalpy (Total Heat) — Assignment 2-B-1

Objective: 1. Be able to use the steam tables to find:

   a. Enthalpy of the liquid
   b. Enthalpy of evaporation
   c. Enthalpy of steam

Information: The dry-saturated-steam tables are divided into a number of columns. The first two you may be familiar with. They are the ones that show the pressure-temperature relationship of dry saturated steam. For each pressure there is a corresponding temperature. The columns are headed by the letters (t) for temperature, in degrees Fahrenheit, and (p) for pressure, in pounds per square inch absolute.

The three columns under enthalpy are the ones that give you the heat in the saturated liquid, the heat of evaporation, and the heat in the saturated vapor. It can be shown as:

Heat in Liquid + Heat of Evaporation = Heat in Saturated Vapor

As the pressure on a boiler increases, the temperature of the water and steam increases, and the boiling point increases. The enthalpy of the saturated liquid also increases. But the enthalpy of evaporation decreases. The enthalpy of the saturated vapor increases up to 466.9 p.s.i.a. and 460°F. It then slowly decreases. This can be followed on the dry-saturated-steam tables.

1. Boiling point changes with pressure.
2. Heat in liquid increases with pressure (sensible heat).
3. Heat of evaporation decreases with pressure (latent heat).
4. Total heat in vapor increases, then decreases.
5. Total heat in normal operating range – approximately 1200 Btu per pound

Reference: Saturated Steam Tables from
Steam Plant Operation
or *Elementary Steam Power Engineering*

Procedure: After studying the above information and the references, complete the following assignment.

Assignment:

1. Show from the steam tables that boiling point increases with pressure.
2. How does pressure affect the heat of:
    a. The liquid
    b. Evaporation
    c. The vapor
3. Using the steam tables, construct four graphs in different colors, showing:
    a. Pressure-temperature relationship
    b. Enthalpy of liquid
    c. Enthalpy of evaporation
    d. Enthalpy of vapor

Specific Volume of Steam — Assignment 2-B-2

Objective: Be able to use the steam tables to find:

a. Specific volume of the saturated liquid
b. Specific volume of the saturated vapor

Information: From our previous lesson you know that the saturated steam tables are divided into various columns. The third and fourth deal with the specific volume of saturated steam. For each pressure there exists a definite specific volume for the saturated liquid and the saturated vapor. (Note: specific volume is given in cubic feet per pound.)

As the pressure on a boiler increases, the specific volume of the liquid increases. This is not due to the pressure directly but to the corresponding increase in temperature. The specific volume of the saturated vapor decreases with an increase in pressure. This is shown quite clearly in the saturated steam tables.

With an increase in pressure —

1. Specific volume of the saturated liquid increases.
2. Specific volume of the saturated vapor decreases.

References: Saturated Steam Tables from *Steam Plant Operation*
or *Elementary Steam Power Engineering*

Procedure: After studying the above information and the references complete the following assignment.

Assignment:

1. How does pressure affect the specific volume of the saturated liquid and the saturated vapor in a steam boiler?

2. Using the steam tables, construct two graphs to show the specific volume at various pressures for —
   a. Saturated liquid.
   b. Saturated vapor.

3. What units are used to express the specific volume?

Interpolation

Assignment 2-B-3

Objective: To know how to interpolate between values for enthalpy and the specific volume of dry saturated steam.

Information: The steam tables may not give you the exact number you need. You may have to interpolate between two given numbers to get it.

Let us review the interpolation of enthalpy values as given in the Science Manual 2.

Example 1: The steam pressure is 24 p.s.i.a. Find the:

a. Enthalpy of liquid
b. Enthalpy of evaporation
c. Enthalpy of vapor

To interpolate, proceed as follows, taking values from the dry-saturated-steam tables.

a. To find the enthalpy of saturated liquid –

	Pressure in p.s.i.a.		**Enthalpy in Btu per pound**	
4	20	5	196.16	12.26
	24			
	25		208.42	

24 – 20 = 4   208.42 – 196.16 = 12.26
25 – 20 = 5

Multiply $\frac{4}{5} \times 12.26 = 9.808$

Then add 196.16 + 9.808 = 205.968

The enthalpy of saturated liquid for steam at 24 p.s.i.a. is therefore 205.968 Btu's per pound.

b. To find the enthalpy of evaporation of dry saturated steam at 24 p.s.i.a. –

	Pressure in p.s.i.a.		**Enthalpy in Btu per pound**	
4	20	5	960.1	8.0
	24			
	25		952.1	

$\frac{4}{5} \times 8 = 6.4$

Since the enthalpy of evaporation *decreases* as the pressure *increases,* we subtract 6.4 from 960.1.

$$960.1 - 6.4 = 953.7$$

The enthalpy of evaporation at 24 p.s.i.a. is therefore 953.7 Btu's per pound.

c. To find the enthalpy of dry saturated steam at 24 p.s.i.a. –

Pressure in p.s.i.a.			Enthalpy in Btu's per pound	
4	20	5	1156.3	4.3
	24			
	25		1160.6	

$$\frac{4}{5} \times 4.3 = 3.44$$

Add:
$1156.3 + 3.44 = 1159.74$ Btu per pound.
The enthalpy of dry saturated steam at 24 p.s.i.a. is therefore 1159.74 Btu's per pound.

To find the specific volume of dry saturated steam at pressures other than those given in the steam tables, it is again necessary to interpolate values.

Example 2: Find the specific volume of
a. Liquid
b. Vapor
of dry saturated steam at 102 p.s.i.a.

a. To find the specific volume of liquid at 102 p.s.i.a. –

Pressure in p.s.i.a.			Specific volume in cu. ft. per lb.	
2	100	10	.01774	.00008
	102			
	110		.01782	

$$\frac{2}{10} \times .00008 = .000016$$

Add:

$.01774 + .000016 = .017756$ cu. ft./lb. The specific volume of liquid at 102 p.s.i.a. therefore equals .017756 cu. ft./pound.

b. To find the specific volume of vapor at 102 p.s.i.a. –

Pressure in p.s.i.a. **Specific volume in cu. ft. per lb.**

$$\left.\begin{matrix} 2\left[\begin{matrix}100\\102\end{matrix}\right. \\ 110\end{matrix}\right]10 \qquad\qquad \left.\begin{matrix}4.432\\ \\4.049\end{matrix}\right]{.383}$$

$$\frac{2}{10} \times .383 = .0766$$

$$4.432 - .0766 = 4.3554$$

The specific volume of the vapor at 102 p.s.i.a. therefore equals 4.3554 cu. ft./pound.

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Procedure: After studying the above information and references, complete the following assignment.

Assignment:

Find –

a. Enthalpy of saturated liquid
b. Enthalpy of evaporation
c. Enthalpy of vapor
d. Specific volume of saturated liquid
e. Specific volume of vapor

for the following pressures (all in p.s.i.a.)

1. 45
2. 113
3. 153
4. 196
5. 264

Show all your work.

Objectives: Be able to describe the types of forces found in mechanics.

Be able to solve problems involving forces.

Information: From our previous lessons on forces, we know that a force is defined as a push or a pull. There are different types of forces, depending on how the force is applied.

A compression force is a force that is applied to an object that tends to press on it or squeeze it. An example of this would be a vertical beam in a building, being compressed by the weight of parts above it and the reacting force from below.

A shearing force is a force that tends to shear or cut through a material. An example of this would be a rivet in a boiler seam that might be cut through by the pressure of the two parts of the seam being forced apart by the pressure inside.

Tensile force is one you should be familiar with from problems on M.A.W.P. It is a force that tends to stretch an object – such as the steam pressure in a steam boiler, that tends to stretch the metal.

Forces can act on an object in several ways:

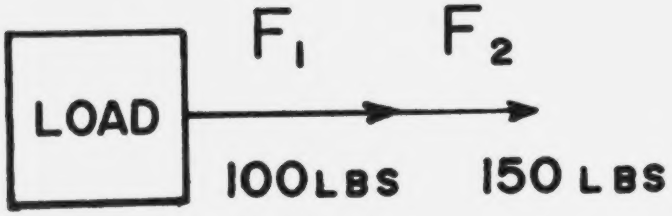
a. In the *same* direction, so that the resultant force is the sum of the forces (2-C-1-1).

b. In the *opposite* direction, so that the resultant force is the difference between the forces (2-C-1-2).

c. *At an angle* to each other, so that the resultant has to be found by the resolution of all forces acting on the object. Sketch 2-C-1-3 shows two forces, X and Y, acting on the load at an angle to each other. When X is resolved into F_1 and F_1', and Y is resolved into F_2 and F_2', the sum of F_1 and F_2 is the resultant along the horizontal axis. And the difference between F_1' and F_2' is the resultant on the vertical axis.

Note: In problems of this type, a graph can be drawn to scale, and with care accurate results can be obtained.

FORCES IN SAME DIRECTION

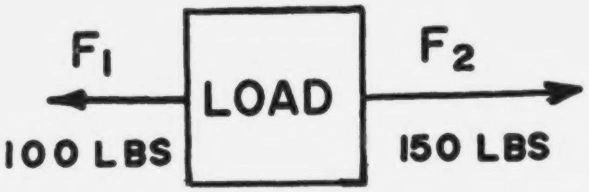

F1
F2
LOAD
100 LBS
150 LBS

$$F_R = F_1 + F_2$$

$$F_R = 100 + 150$$

$$F_R = 250 \text{ LBS}$$

2-C-1-1


F1
LOAD
F2
100 LBS
150 LBS

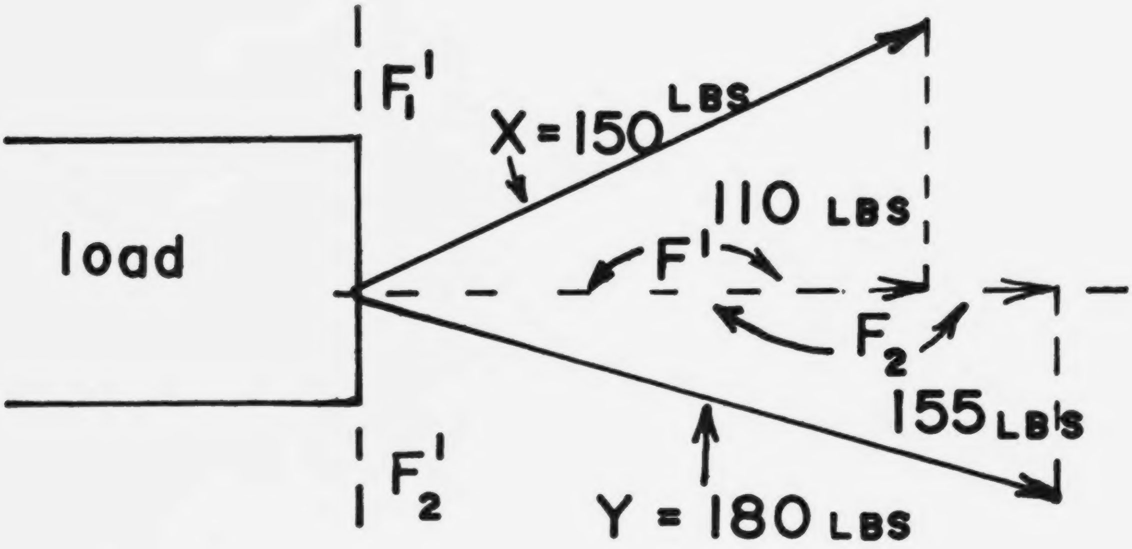
$$F_R = F_2 - F_1$$

$$F_R = 150 - 100$$

$$F_R = 50 \text{ LBS}$$

FORCES IN OPPOSITE DIRECTION

2-C-1-2


load
F_1'
X = 150 LBS
110 LBS
F'
F_2
155 LBS
F_2'
Y = 180 LBS

$$\begin{aligned} F_R &= F_1 + F_2 \\ &= 110 + 155 \\ &= 265 \text{ LBS} \end{aligned}$$

RESOLUTION OF FORCES
ACTING ON AN OBJECT

2 - C - 1 - 3

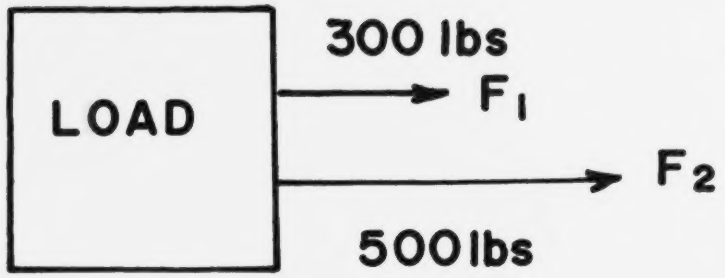
Reference: *Basic Physics*

Procedure: After studying the information and the reference, complete the following assignment.

Assignment:

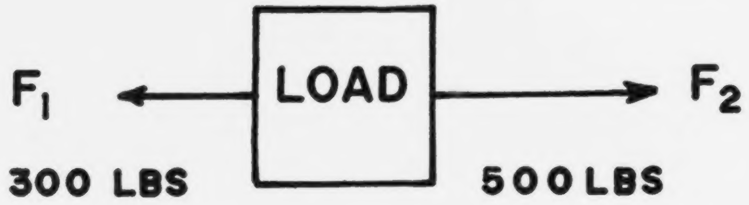
1. Name the types of forces and give a description of each.
2. Find the resultant forces as indicated on sketch 2-C-1-4.

A


300 lbs
LOAD
F1
F2
500 lbs

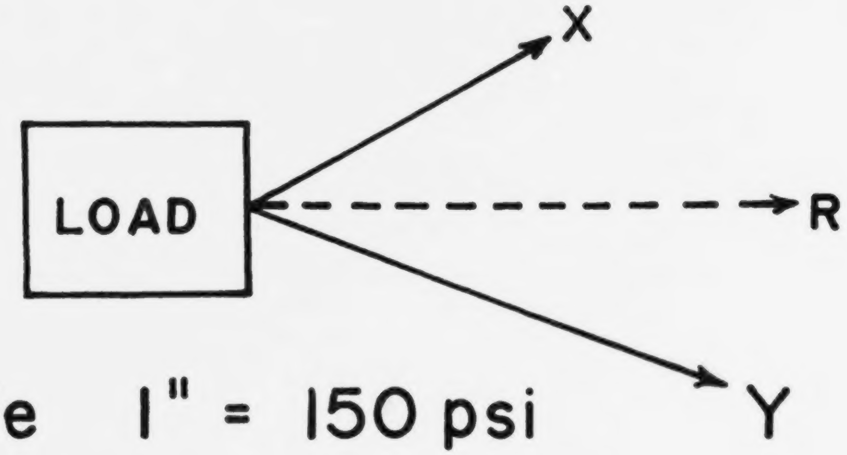
RESULTANT =

B


F1
LOAD
F2
300 LBS
500 LBS

RESULTANT =

C



NOTE: scale 1" = 150 psi

RESULTANT =

Objectives: Be able to describe the classes, purposes, and uses of levers.

Be able to solve problems involving forces on levers.

Information: A lever may be defined as a bar that has both resistance and effort applied to it, and is free to move around a point, called a fulcrum. Shown in Sketch 2-C-2-1.

There are several classes of levers.

1. Class 1 is the basic lever shown in Sketch 2-C-2-1.
2. Class 2 is when the resistance and effort are applied on the same side of the fulcrum, with the effort at the greater distance from the fulcrum. It is shown in Sketch 2-C-2-2
3. Class 3 is similar to class 2, except that the effort is applied between the fulcrum and the resistance. This is shown in Sketch 2-C-2-3.

The purpose of most levers is to obtain a mechanical advantage, that is, to overcome a large resistance with a smaller force. The principle of levers is used in tools such as crowbars, pliers, and wrenches. Such items as wheelbarrows, cranes, etc. may also be considered to be levers.

In solving problems involving levers, we may use the *law of moments.* It states that the sum of the clockwise moments must equal the sum of the counterclockwise moments if the lever is to be in equilibrium (balanced, with no motion). A **moment** is the product of a force by its distance from the fulcrum. Moments are illustrated in Sketch 2-C-2-4.

Example: What effort has to be applied to hold the lever in Sketch 2-C-2-4 in equilibrium if:

d_E = 125 feet

d_R = 25 feet

R = 100 pounds

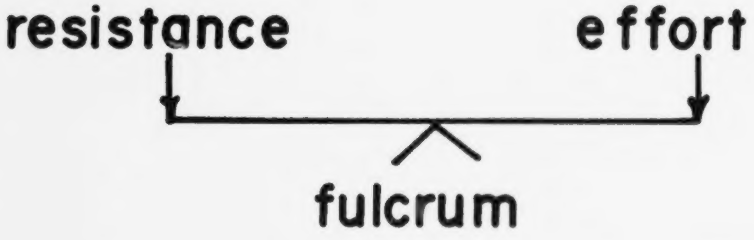
$$R \times d_R = E \times d_E$$

$$E = \frac{R \times d_R}{d_E}$$

$$E = \frac{100 \times 25}{125} = 20 \text{ pounds}$$

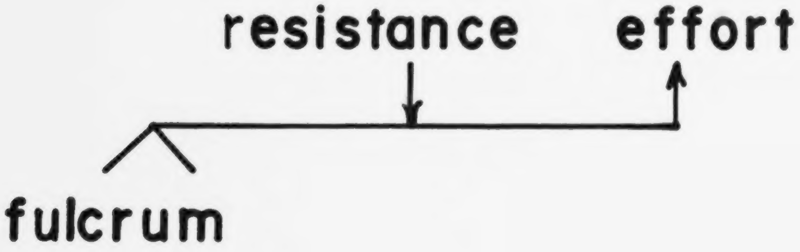
Reference: *Basic Physics*

BASIC LEVER


resistance
effort
fulcrum

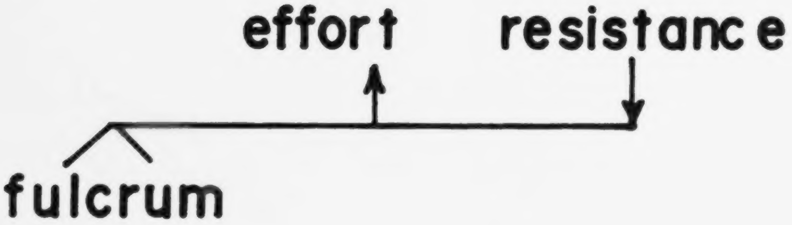
class - 1

2-C-2-1


resistance
effort
fulcrum

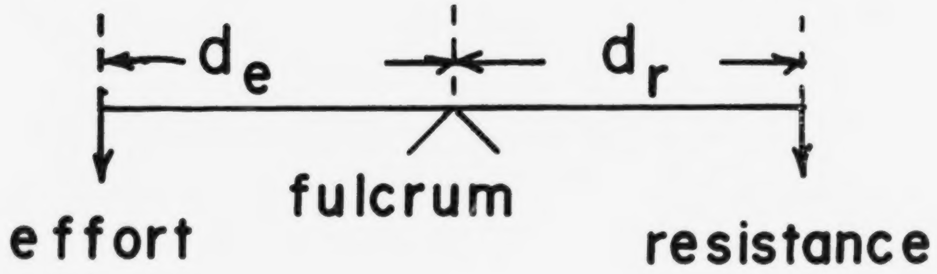
class - 2

2-C-2-2


effort
resistance
fulcrum

class - 3

2-C-2-3


d_e
d_r
effort
fulcrum
resistance

clockwise moments = counterclockwise moments

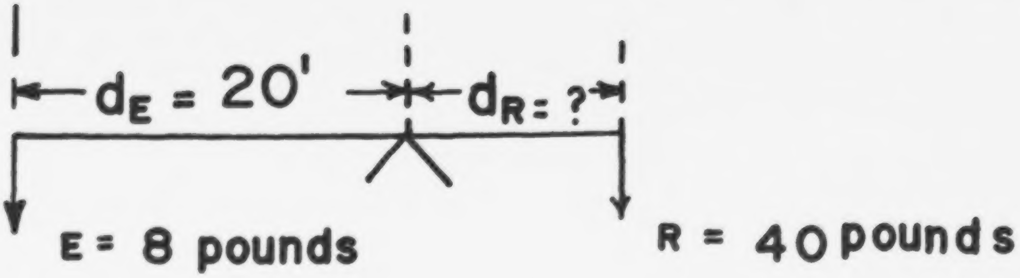
$$R \times d_r = E \times d_e$$

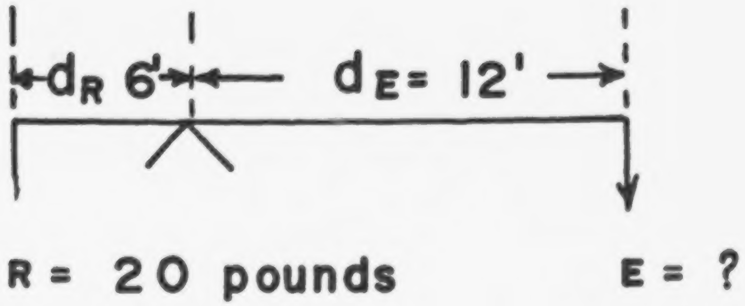
2-C-2-4

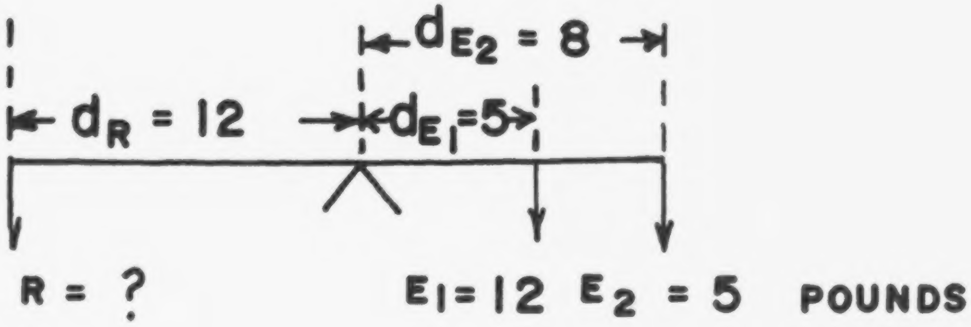
Procedure: After studying the information and reference, complete the following assignment.

Assignment:

1. Describe each class of lever.
2. What uses are made of levers?
3. Name several labor-saving devices using the lever principle, and state the class they fall into.
4. Find the missing values in Sketch 2-C-2-5.


$d_E = 20'$
$d_R = ?$
E = 8 pounds
R = 40 pounds


d_R 6'
$d_E = 12'$
R = 20 pounds
E = ?


$d_{E_2} = 8$
$d_R = 12$
$d_{E_1} = 5$
R = ?
$E_1 = 12$ $E_2 = 5$ POUNDS

Objective: Be able to describe the principle of torque of rotating elements.

Information: Torque is stress on a body which tends to cause it to turn. Torque produces rotary motion. It is measured in either inch-pounds or foot-pounds. A foot-pound of torque is exerted by a force of one pound acting at a radius of one foot. (Shown in Sketch 2-C-3-1)

The torque of any rotating element is its turning moment, and is measured by the product of the force and the perpendicular distance from the axis of rotation to the line of action of the force.

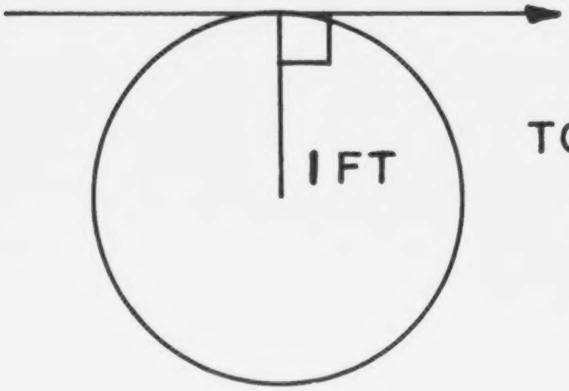
TORQUE = FORCE X RADIUS
TORQUE = 500 lbs. X 9 inches
TORQUE = 4500 inch-pounds (Shown in Sketch 2-C-3-2)

Reference: *Basic Physics*

Procedure: After studying the information and reference, answer the following questions and be prepared to discuss each one.

Assignment:

1. What is torque?
2. Describe torque with the use of a sketch.
3. Set up and solve a problem involving torque.
4. Explain how a torque wrench functions.



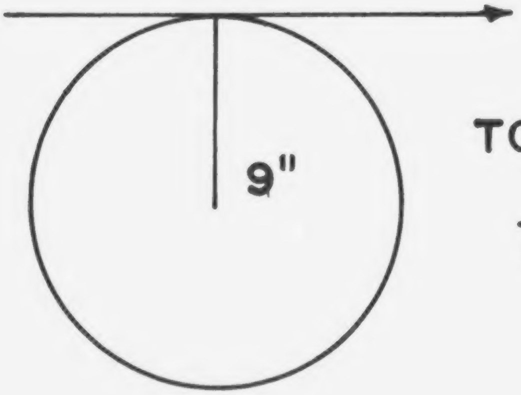
TORQUE = FORCE X RADIUS

Tq = F X R

= 1 LB. X 1 FT.

= 1 FOOT-POUND

2-C-3-1



TORQUE = FORCE X RADIUS

Tq = F X R

= 500 LBS. X 9 INCHES

= 4500 IN. LBS.

TORQUE

2-C-3-2

Objectives: Be able to describe the principle of the inclined plane.

Be able to solve problems involving the inclined plane.

Information: The inclined plane is a simple machine that is formed by two surfaces at an acute angle to each other (Shown in sketch 2-C-4-1)

The principle involved when a load is moved from the bottom to the top of the inclined plane is that you move the load through a *greater distance* with a *smaller force* than would be required if it were lifted vertically.

If we let (L) equal the incline length, (H) the vertical height, (R) the resistance due to the load and (F) the force needed to move the load, it follows that

$$\text{Force} \times \text{Length} = \text{Resistance} \times \text{Height}$$

$$F \times L = R \times H \text{ (Shown in sketch 2-C-4-2)}$$

The above formula ignores the extra force needed to overcome friction.

Problems involving the inclined plane can be solved using the above formula.

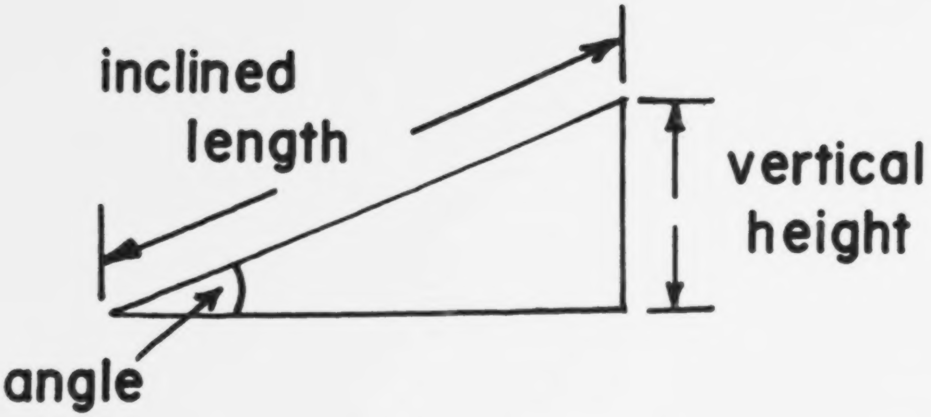
Example 1: Find the force that is needed to move a 100-pound weight 12 feet along an inclined plane to a point 5 feet off the ground.

$$F \times L = R \times H$$

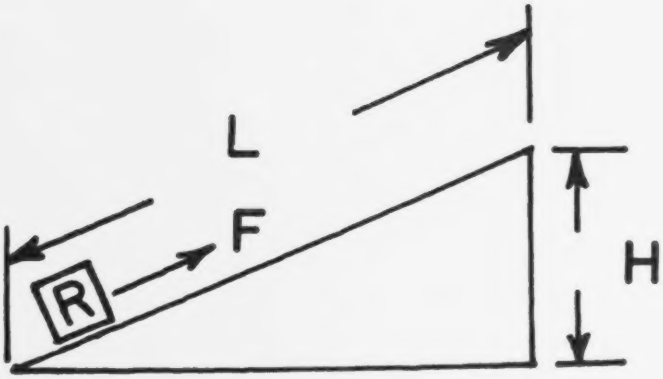
$$F = \frac{R \times H}{L}$$

$$F = \frac{100 \times 5}{12}$$

$$F = \frac{500}{12} = 41\frac{2}{3}$$


inclined length
vertical height
angle

2-C-4-1



$F \times L = R \times H$

2-C-4-2

INCLINED PLANE

Example 2: Find the vertical height of an inclined plane, given the following information: force of 25 pounds; resistance of 200 pounds; and length of slope of 40 feet.

$$F \times L = R \times H$$

$$H = \frac{F \times L}{R}$$

$$H = \frac{25 \times 40}{200}$$

$$H = 5 \text{ feet}$$

Reference: *Basic Physics*

Procedure: After studying the information and reference, do the following assignment.

Assignment:

1. What is the principle of the inclined plane?

2. Name the parts of an inclined plane and express them in an equation.

3. Solve for the missing data:

	F	L	R	H
a.	15 lbs.	?	150 lbs.	5 ft.
b.	?	40 ft.	200 lbs.	4 ft.
c.	50 lbs.	75 ft.	300 lbs.	?
d.	75 lbs.	60 ft.	?	3 ft.

Objectives: Be able to describe the principle of the wheel and axle.

Be able to solve problems involving the wheel and axle.

Information: The wheel and axle is a simple machine that is formed by an outer circular rim (wheel) fastened to an inner rim (axle), as shown in Sketch 2-C-5-1.

When a small force is applied to the outer rim, it can lift a larger load on the inner rim. A basic example of this would be when a water bucket is cranked out of a well. The rotating handle forms the outer rim, where the force is applied, and the axle is the shaft that the rope winds on. If we think of the center of the axle as the fulcrum, it then follows that the moment of the force is equal to the moment of the resistance.

Moment of Force = Moment of Resistance (Shown in sketch 2-C-5-1)

If we let (F) represent force, (d_F) the distance the force is acting through, (R) the resistance that the force is acting against, and (d_R) the distance the resistance acts through, then

Moment of Force = Moment of Resistance, or

$$F \times d_F = R \times d_R$$

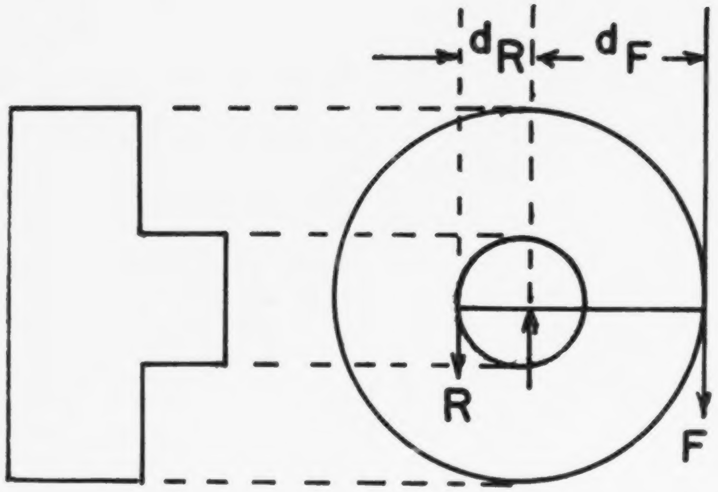
Problems involving the wheel and axle can be solved using the above formula. (Once again we ignore friction.)

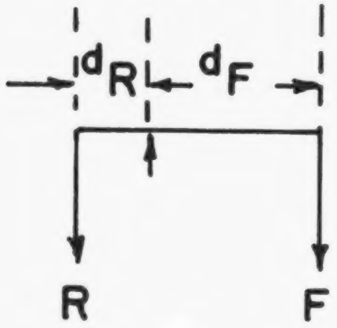
Example 1: What force is required to lift a 40-pound bucket of water from a well when the handle is 18 inches long and the shaft is 6 inches in diameter?

$$F \times d_F = R \times d_R$$

$$F = \frac{R \times d_R}{d_F}$$

$$F = \frac{40 \times 3}{18} = 6\frac{2}{3} \text{ pounds}$$





$$R \times d_R = F \times d_F$$

WHEEL and AXLE

2-C-5-1

Example 2: How much load can be lifted with a force of 20 pounds, a wheel diameter of 3 feet, and an axle diameter of 6 inches?

$$F \times d_F = R \times d_R$$

$$R = \frac{F \times d_F}{d_R}$$

$$R = \frac{20 \times 18}{3} = 120 \text{ pounds}$$

Reference: *Basic Physics*

Procedure: After studying the information and reference, do the following assignment.

Assignment:

1. Describe the principle of the wheel and axle.

2. How is it similar to the lever?

3. Solve for the missing data:

	F	D_F	R	D_R
a.	10 lb.	2 ft.	?	.5^R ft.
b.	?	3 ft.	80 lb.	1 ft.
c.	20 lb.	?	100 lb.	9 inch
d.	30 lb.	2.5 ft.	150 lb.	?

Objectives: Be able to describe the principles and properties of fluids.

Be able to solve simple problems involving hydraulics.

Information: A fluid is any substance that will flow, such as a liquid or a gas. Fluids take the shape of the container that they are in regardless of its shape. When pressure is applied to a fluid, it is transmitted in all directions. This is the principle used in the hydraulic press and in the dead-weight pressure-gage tester.

The Sketch 2-C-6-1 shows how this principle is used in the hydraulic press. It can be shown that (if we neglect friction) the following equation is true:

$$F \times d = F' \times d'$$

If we know the values of any three, we can find the fourth.

Example 1: A 25-pound force is applied to a piston that moves 12 inches. Another piston connected to the same hydraulic system moves only ½ inch. How much force is being exerted on the second piston?

$$F \times d = F' \times d'$$

$$F' = \frac{F \times d}{d'}$$

$$F' = \frac{25 \times 12}{.5} = 600 \text{ pounds}$$

Reference: *Basic Physics*

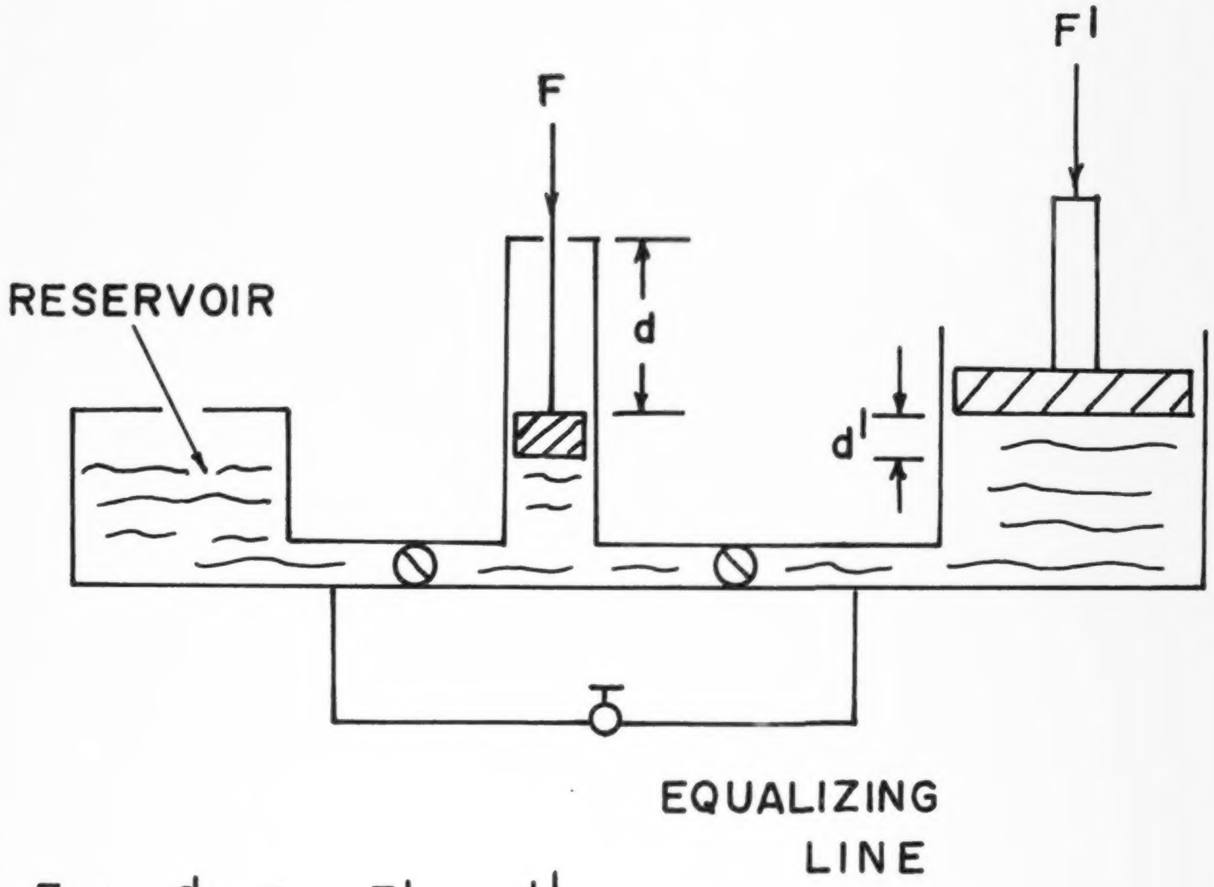
Procedure: After studying the information and reference, complete the following assignment.

Assignment:

1. What is a fluid?

2. Give some properties of fluids.

(Assignment continued on page 42.)


F'
F
RESERVOIR
d
d'
EQUALIZING LINE

$$F \times d = F' \times d'$$

F = force on small piston

F' = force on large piston

d = distance travelled by small piston

d' = distance travelled by large piston

FLUID PRESSURE

3. Solve the following for the missing data:

	F	d	F′	d′
a.	10 lbs.	14 inches	?	.25 inch
b.	50 lbs.	?	1500 lbs.	.1 inch
c.	100 lbs.	10 inches	2000 lbs.	?
d.	?	15 inches	3000 lbs.	.4 inch

Objectives: Be able to describe the construction of firetube and watertube boilers.

Be able to relate the details of construction to safety and efficiency.

Information: By this time you should be able to look at a boiler and be able to tell if it is a firetube or a watertube boiler. The firetube boiler will have the heat and gases of combustion pass through tubes surrounded by water. The tube sheets will be flat and require stays for support. They will be used in smaller plants that do not require large fluctuating steam loads. With modern technology there are firetube boilers that are rated up to 700 to 750 boiler horsepower. The modern firetube boiler will be of welded construction. This will reduce danger of caustic embrittlement due to poorly caulked joints. The welded joints, being 100% efficient, also allow the firetube boiler to carry a higher M.A.W.P.

The watertube boiler has water inside the tubes — the gases of combustion pass around the tubes. The steam and water drum is dished and therefore requires no braces or stays. The watertube boiler carries a smaller volume of water and is therefore capable of handling a larger steam load; it can respond quickly to fluctuating steam loads. Because of the construction, these boilers can carry extremely high pressures of 2800 p.s.i., with large degrees of superheat. They are less liable to disastrous explosions, but they require more skilled operators.

References: *Steam Plant Operation*
Boiler Room Questions and Answers
Elementary Steam Power Engineering

Procedure: After reading the information and references, answer the following questions.

Assignment:

1. Describe in detail the cause of a boiler explosion.
2. Why do firetube boilers require stays?
3. Why are the tubes in a watertube boiler made of thinner metal than the steam and water drum?
4. What is meant by M.A.W.P. and how is it determined?
5. Why are modern boilers all built with welded construction?

Objective: Be able to describe waterwall construction and explain its advantages.

Information: If you will go back to your Science Manual #2, Units 3-A-2 and 3-A-3, you will find that the classification and construction of firetube boilers were covered pretty completely. The package-type Scotch marine boiler has become very popular, and almost every boiler manufacturer has one to offer with its own pet modifications. When choosing one, always try to find out which company offers the best service.

In Units 3-B-1, 3-B-2, and 3-B-3, we discussed development, classification, and basic construction of watertube boilers. At this time it is important to discuss the addition of waterwalls. As boilers grew in size, steam pressures increased, and so did furnace temperatures. This lead to increased maintenance of brickwork. By installing water walls, the spauling and erosion of brickwork was considerably reduced; it also allowed for smaller furnace volume, resulting in higher heat release and reduced excess air. Without the use of waterwalls, the development of stokers and pulverized-coal burners could never have happened.

Section I paragraph 70, page 49 of the ASME Code has a table showing this very clearly.

Waterwall heating surface — minimum pounds of steam per hour per square foot of heating surface:

Hand-fired coal	8
Stoker-fired coal	12
Oil — Gas — Pulverized fuel	16

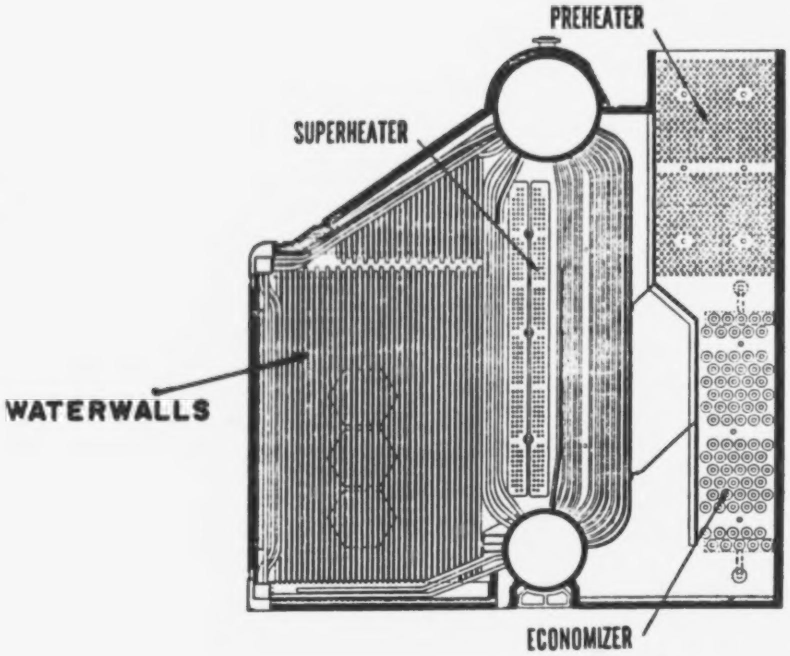
References: *Steam Plant Operation*
Elementary Steam Power Engineering

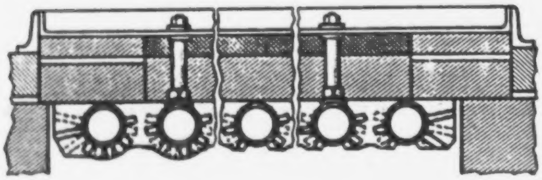
Procedure: After studying the information and references, answer the following questions and be ready to discuss them in class.

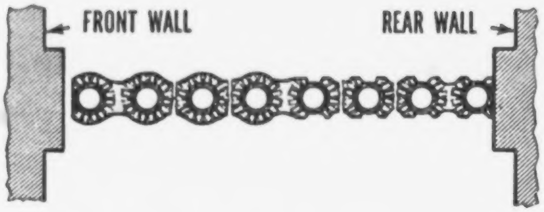
Assignment:

1. Discuss the reasons for using waterwalls.
2. When can you blow down your water walls? Explain.

(Assignment continued on page 46.)


PREHEATER
SUPERHEATER
WATERWALLS
ECONOMIZER




FRONT WALL
REAR WALL

WATERWALLS

3-A-2-1

3. In a watertube boiler with waterwalls, what is the minimum pounds of steam per hour per square foot of heating surface when burning a pulverized fuel?

4. A B & W Boiler uses pulverized coal and has 2000 square feet of waterwall heating surface. Find the number of pounds of steam per hour that is being produced.

Mechanical Inspection Bureau and A.S.M.E. Codes — Assignment 3-A-3

Objective: Be familiar with all subchapters of the New Jersey Mechanical Inspection Bureau Code.

Be able to explain the parts of the A.S.M.E. Code that covers construction and care of power boilers.

Information: When you sit for and pass your license for a Black Seal Operator-in-Charge license, you may act as the chief engineer in a plant of up to 500 boiler horsepower. Do you know just what that means? It means you are the person responsible for making decisions.

Which equipment requires a licensed operator? What documents must be posted, and where? Who can make boiler and pressure-vessel repairs? Registration number — how do you get one for a new boiler? Where is the number displayed? What are the rules covering steam boiler blowoff tanks? And so on.

This is a big responsibility, and the answer *"I don't know"* will not be accepted. You are supposed to know because you are the chief!

Remember, a good engineer does not know everything, but you should know *where to find out about anything.* Keep a copy of the Code Book in your desk, your file, or back pocket. Read it; look it over often; it could save you a lot of embarrassment and possibly a fine for violating a state regulation.

Reference: *Mechanical Inspection Bureau Code*
A.S.M.E. Code, Section I and VII

Procedure: After studying the information and references, answer the following questions and be prepared to discuss each in class.

Assignment:

1. Make a list of all subchapter headings of the Mechanical Inspection Bureau Code.

2. Discuss the following for boiler construction and inspection:
   - a. Annual internal and external inspections
   - b. Insurance company inspection fees
   - c. State inspection fees
   - d. Posting inspection certificate

3. Discuss the following for engineer's and operator's licenses:
    a. Failure to appear at examination
    b. License classification
    c. Acting chief engineer
    d. Scope of operator in charge
    e. Scope of third-grade license
    f. Scope of second-grade license
    g. Scope of first-grade license

4. Discuss the recommendation of A.S.M.E. Code Section VII:
    a. Before lighting a fire
    b. Purging boiler furnace
    c. Cutting steam generators into service

5. Discuss the recommendation of A.S.M.E. Code Section I for general requirements:
    a. Pressure gages
    b. Requirements for blowoff piping

Objective: Be able to describe the types of stresses acting upon boiler parts.

Information: **Stress** may be defined as a force tending to cause a break in a material divided by the area of the material that resists the break.

$$\text{STRESS} = \frac{\text{FORCE (Tending to break)}}{\text{AREA (Resisting break)}}$$

The three basic stresses that you will have to know in stationary engineering are: compression stress, shearing stress, and tensile stress.

Compression — When two forces act together, pushing toward the center (Sketch 3-B-1-1).

Shearing — Two forces acting together, tending to cut — like a pair of shears. (Sketch 3-B-1-2).

Tensile — Two forces of equal intensity acting in opposite directions (Sketch 3-B-1-3).

Boiler plates and staybolts are subjected to tensile stress. Rivets are subjected mostly to a shearing stress.

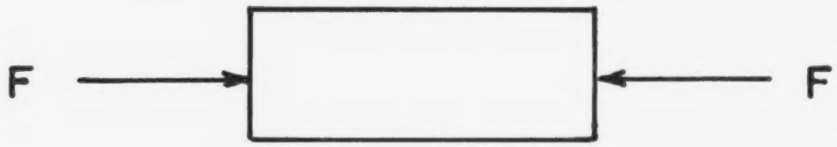
Only first quality steel is used for boiler construction. It must be able to withstand boiler pressure and also boiler temperature. The temperature will have a more serious effect upon the boiler than pressure. Excessive temperature must be guarded against as well as excessive pressure. A good grade of steel will maintain and even increase in strength up to about 700°F. Higher temperatures cause a rapid decrease in the strength of ordinary steel.

The tensile strength of steel used in the construction of boilers will vary from 50,000 to 100,000 p.s.i. Its elastic limit is 25,000 p.s.i. to 55,000 p.s.i. and shearing strength of 40,000 p.s.i. to 48,000 p.s.i.

Reference: *Basic Physics*
Steam Plant Operations

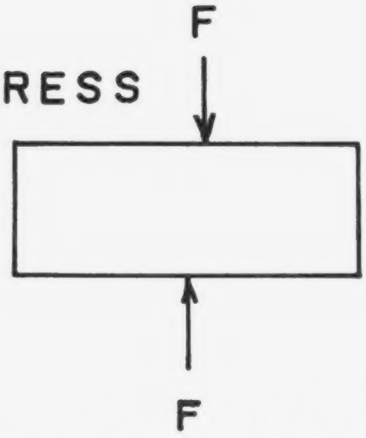
Procedure: After studying the information and the listed references, complete the following assignment.

COMPRESSION STRESS



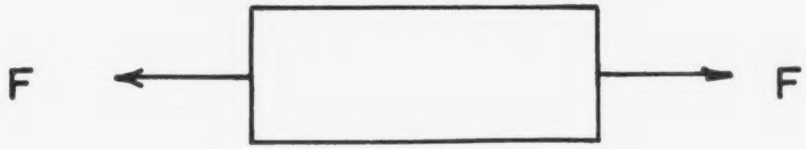
3-B-1-1

SHEARING STRESS



3-B-1-2

TENSILE STRESS



3-B-1-3

THREE TYPES OF STRESS

Assignment:

1. Define the following:
   a. stress
   b. tensile stress
   c. compression stress
   d. shear stress

2. What types of stresses are boiler plates, staybolts and rivets subjected to?

3. Why is only first-quality steel used in boiler construction?

4. Which has the more serious effect upon the boiler, temperature or pressure?

5. Show by sketch the following:
   a. tensile stress
   b. compression stress
   c. shearing stress

Maximum Allowable Working Pressure and Factor of Safety

Assignment 3-B-1-M1

Objective: Be able to determine the maximum allowable working pressure on a steam boiler.

Information: To find the maximum allowable working pressure on a boiler, you will have to use the following formula.

$$\text{M.A.W.P.} = \frac{S \cdot T \cdot E}{F \cdot R}$$

Where:
S = The tensile strength of the metal
T = The thickness of the metal
E = The efficiency of the joint
F = Factor of safety
R = Radius of the boiler drum

Example 1: A 72" boiler shell is ½" thick, and has a tensile strength of 65,000 p.s.i. The joint is 82% efficient, and the factor of safety is 6. Find the M.A.W.P. and the bursting pressure.

Note:

The factor of safety is the ratio of the bursting pressure to the M.A.W.P.

$$\text{M.A.W.P.} = \frac{S \cdot T \cdot E}{F \cdot R}$$

$$\text{M.A.W.P.} = \frac{65000 \times .5 \times .82}{6 \times 36}$$

$$\text{M.A.W.P.} = 123.4 \text{ p.s.i.}$$

$$\begin{aligned} \text{B.P.} &= \text{M.A.W.P.} \times F \\ &= 123.4 \times 6 \\ &= 740.4 \text{ p.s.i.} \end{aligned}$$

Example 2: Using the formula for M.A.W.P., develop the formula for the following:

a. Tensile strength
b. Thickness of shell
c. Efficiency of joint
d. Factor of safety
e. Radius of shell

We will use "P" to stand for M.A.W.P.

$$P = \frac{S \cdot T \cdot E}{F \cdot R}$$

$$P \cdot F \cdot R = S \cdot T \cdot E$$

a. $$S = \frac{P \cdot F \cdot R}{T \cdot E}$$

$$P = \frac{S \cdot T \cdot E}{F \cdot R}$$

$$P \cdot F \cdot R = S \cdot T \cdot E$$

b. $$T = \frac{P \cdot F \cdot R}{S \cdot E}$$

$$P = \frac{S \cdot T \cdot E}{F \cdot R}$$

$$P \cdot F \cdot R = S \cdot T \cdot E$$

c. $$E = \frac{P \cdot F \cdot R}{S \cdot T}$$

$$P = \frac{S \cdot T \cdot E}{F \cdot R}$$

$$P \cdot F \cdot R = S \cdot T \cdot E$$

d. $$F = \frac{S \cdot T \cdot E}{P \cdot R}$$

$$P = \frac{S \cdot T \cdot E}{F \cdot R}$$

$$P \cdot F \cdot R = S \cdot T \cdot E$$

e. $$R = \frac{S \cdot T \cdot E}{P \cdot F}$$

Example 3: A boiler drum is 36" in diameter and has a joint with an efficiency of 87%. The factor of safety is 5. The shell thickness is ¾". The tensile strength of the material is 55,000 p.s.i. find:

a. M.A.W.P.
b. Bursting pressure

$$\text{M.A.W.P.} = \frac{S \cdot T \cdot E}{F \cdot R}$$

$$P = \frac{55000 \times .75 \times .87}{5 \times 18}$$

$$P = 398.75 \text{ p.s.i.}$$

$$\text{B.P.} = \text{M.A.W.P.} \times F$$
$$\text{B.P.} = 398.75 \times 5$$
$$\text{B.P.} = 1993.75 \text{ p.s.i.}$$

Reference: *Steam Plant Operation*
A.S.M.E. Code Books

Procedure: After studying the information and the listed references, complete the following assignment.

Assignment:

1. A boiler drum is 4 feet in diameter. Maximum allowable steam pressure is 220 p.s.i. The efficiency of the joint is 92%, the factor of safety is 5. Shell thickness is ½". Find the tensil strength of the boiler.

2. The diameter of the shell is 3 feet; thickness of the shell 5/8"; M.A.W.P. 280 p.s.i.; tensile strength 65000 p.s.i. The factor of safety is 5. Find the joint efficiency.

3. Boiler shell ½" thick; tensile strength 50,000 p.s.i.; efficiency of joint 80%; factor of safety 5; M.A.W.P. 200 p.s.i. Find the diameter of the shell.

4. Boiler shell 36" in diameter; tensile strength of metal 50,000 p.s.i.; efficiency of joint 80%; factor of safety 5; M.A.W.P. 200 p.s.i. Find the thickness of the plate required.

5. Boiler shell 72" in diameter, ½" thick; tensile strength 65,000 p.s.i.; efficiency of joint 82%; factor of safety 5. Find M.A.W.P. and B.P.

Stays — Assignment 3-B-2

Objective: Be able to describe the types of stays that are used in steam boilers.

State the purposes of the different types of stays.

Information: Stays are found on both watertube and firetube boilers. They are used to reinforce flat surfaces that are subjected to boiler pressure. Examples would be reinforcing tube sheets, combustion chambers, and water legs as found on firetube boilers, and also reinforcing box headers on watertube boilers.

The following stays are still in use in boiler construction: —

a. Hollow
b. Solid
c. Girder
d. Dog

These are shown on sketch 3-B-2-1.

e. Solid through
f. Palm
g. Gusset

These are shown on sketch 3-B-2-2.

Hollow and solid stays are used as staybolts to hold inner and outer wrapper sheets together. The solid staybolt has a telltale hole 3/16 inch in diameter extending 1 inch into the water side of the boiler. If the staybolt fails, water will leak out of the telltale hole, warning the operator. The hollow staybolt has a hole going all the way through.

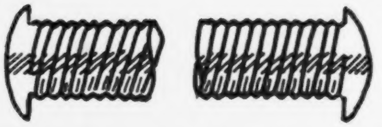
Staybolts are also used to hold together the flat surfaces on a box header.

A girder stay is used to strengthen the flat surface of the crown sheet of a Scotch marine boiler.

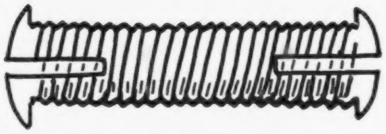
A dog stay is used for man-hole and hand-hole covers.

The solid through stay is used to hold front and rear tube sheets together.

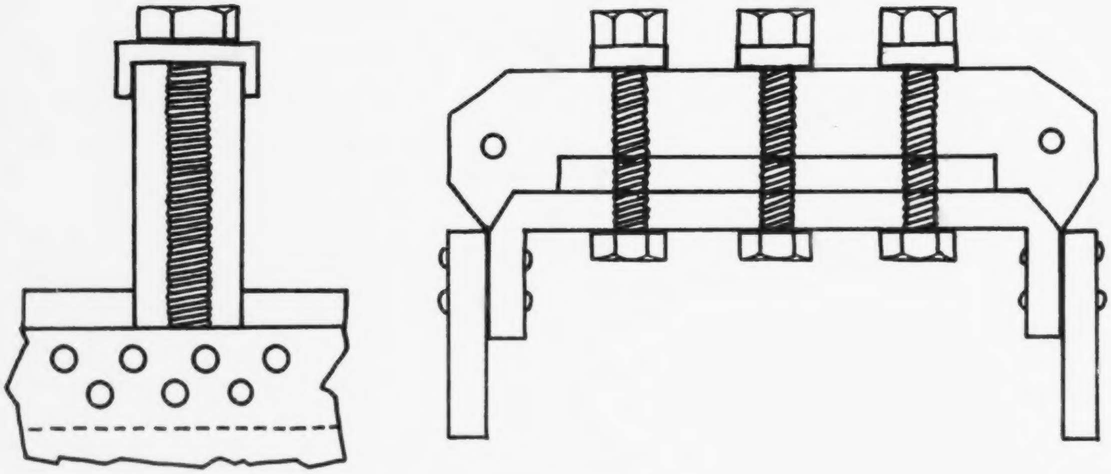
The gusset and palm stays are used to fasten a flat surface to a curved surface, thereby reinforcing the flat surface.



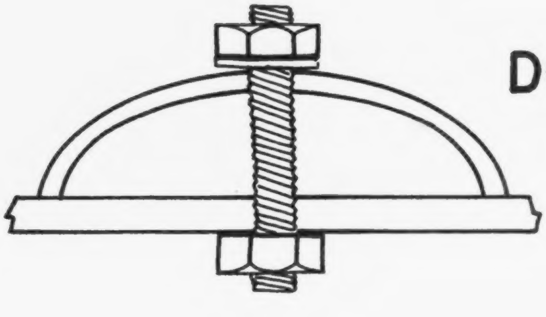
HOLLOW STAY



STAY BOLT

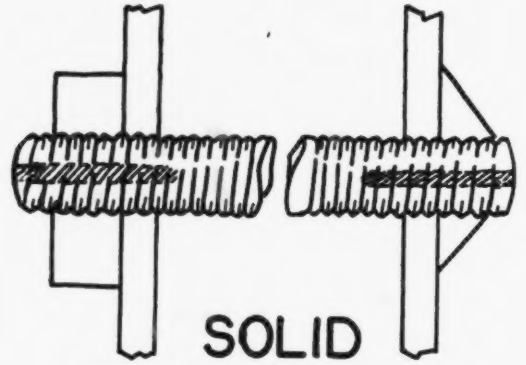


GIRDER STAY

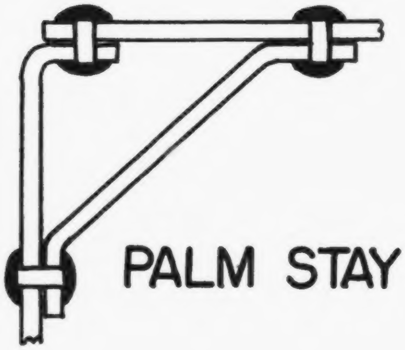


DOG STAY

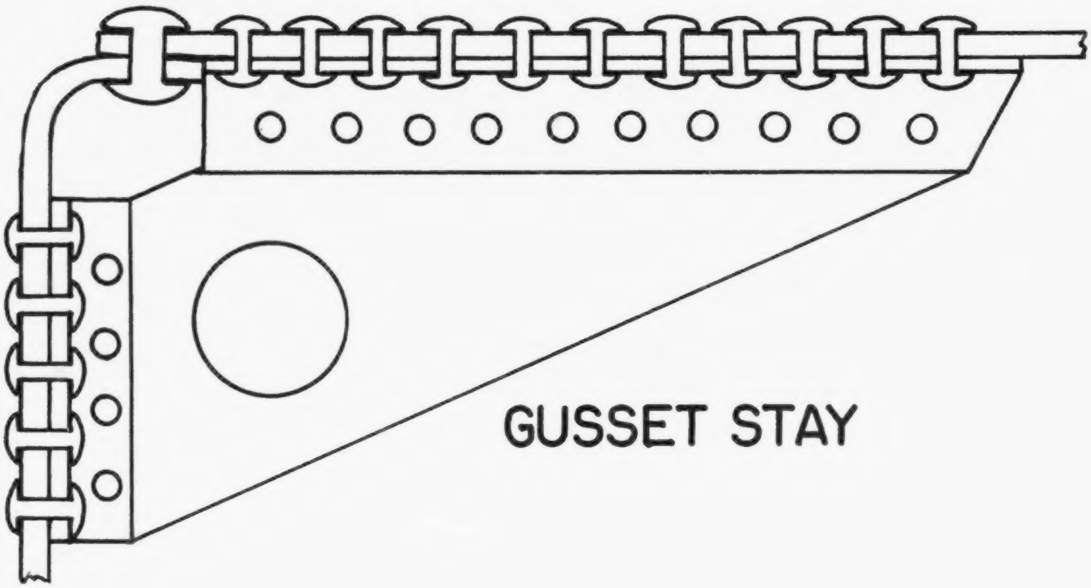
3-B-2-1



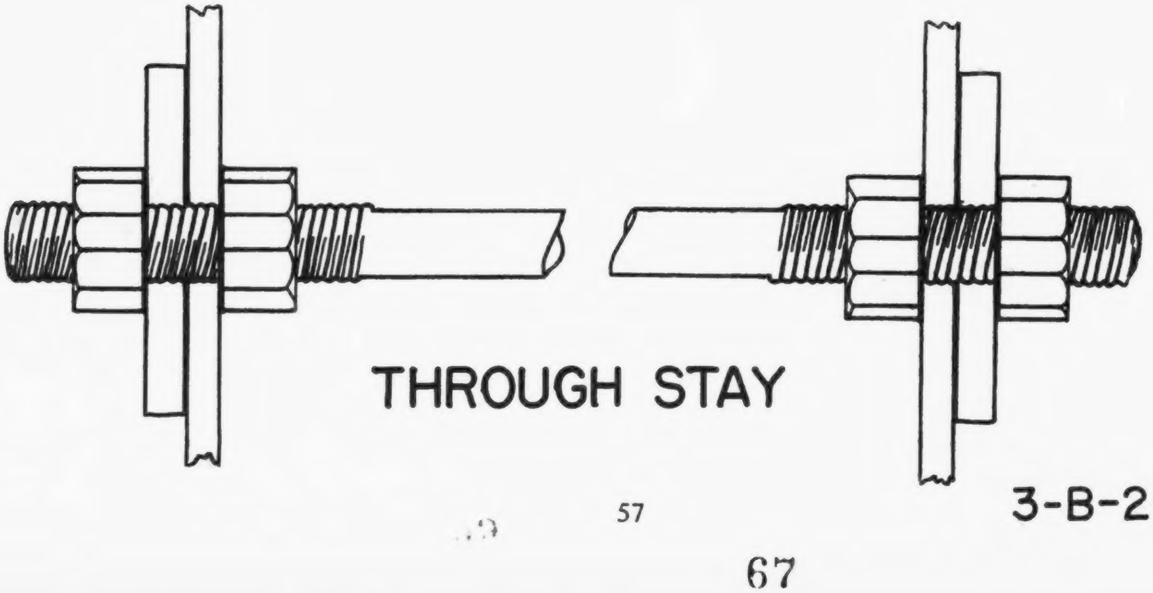
SOLID THROUGH STAY



PALM STAY



GUSSET STAY



THROUGH STAY

3-B-2-2

Reference: *Steam Plant Operation*
Elementary Steam Power Engineering

Procedure: After studying the above information and the listed references, answer the following questions.

Assignment:

1. List all the types of boiler stays.
2. State where each stay is used.
3. Why do staybolts have holes drilled in the ends?
4. What are the dimensions used when the end of a staybolt is drilled?
5. Select a firetube boiler and name the stays you would expect to find in that boiler.

Objective: Be able to determine the safe working pressure on a staybolt.

Information: The safe working pressure on a boiler with a flat surface that is held together by staybolts can be found from the following formula:

$$S.W.P. = \frac{a \times C}{A}$$

NOTE: This is in reference to the diameter of the staybolt, not the thickness of the plate.

S.W.P. = safe working pressure
a = area of the staybolt
C = stress constant of staybolt (found in A.S.M.E. Code)
A = pitch (area covered by 4 staybolts)

To find "A", let us look at sketch 3-B-2-M1. You will note that the area we are interested in is a rectangle using the centers of the staybolts as connecting points. "A" is the product of P and P′.

The area of the staybolt can be found from

$$a = .7854d^2$$

Example 1: A staybolt has a diameter of 2.5″ and is pitched 7″ X 8″. If the stress constant is 9,000 p.s.i., find the S.W.P.

$$S.W.P. = \frac{a \times C}{A}$$

$$= \frac{.7854 \times d^2 \times C}{P \times P'}$$

$$= \frac{.7854 \times 2.5 \times 2.5 \times 9000}{7 \times 8}$$

$$= 788.9 \text{ p.s.i.}$$

Example 2: A staybolt has a diameter of 1.5″ and the pitch is 6″ X 7″. If the stress constant is 8,000 p.s.i., find the S.W.P.

$$S.W.P. = \frac{a \times C}{A}$$

$$= \frac{.7854 \times 1.5 \times 1.5 \times 8000}{6 \times 7}$$

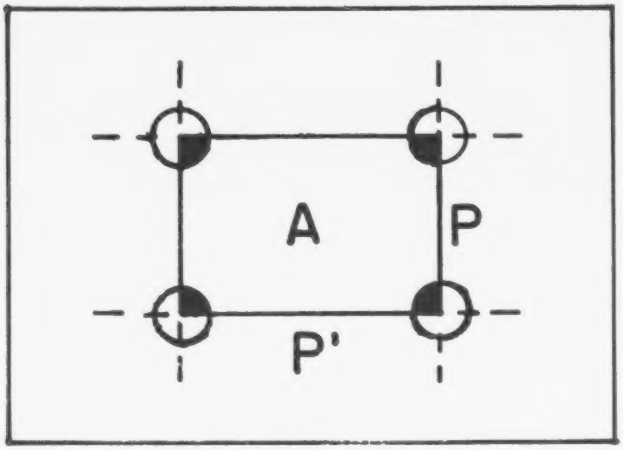
$$= 336.6 \text{ p.s.i.}$$

Reference: *A.S.M.E. Code*

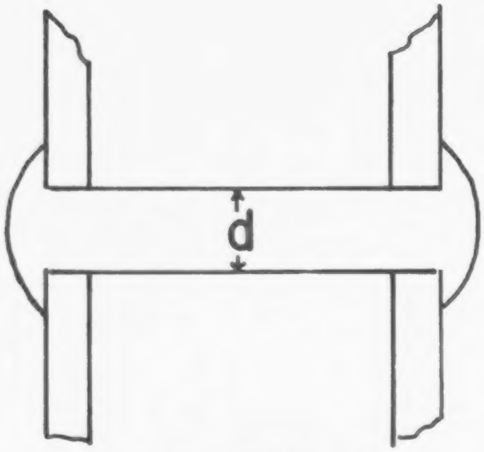
Procedure: After studying the information and reference, work out the answers to the following problems.

Assignment:

1. Find the S.W.P. on a staybolt if the diameter is ¾″ the stress constant is 9500 p.s.i., and the pitch is 4″ X 5″.
2. Find the S.W.P. on a staybolt if the diameter is ½″, the stress constant is 7500 p.s.i., and the pitch is 6″ X 7″.
3. The stress on a staybolt is 4500 p.s.i., the pitch is 3″ X 4″ and the diameter is 5/8″. Find the S.W.P.
4. The diameter of a staybolt is .875″ the stress constant is 9000 p.s.i., and the pitch is 7″ X 8″. Find the S.W.P.



$A=PXP'$



$a=.7854d^2$

AREA SUPPORTED BY A STRAIGHT BOLT

Objective: Be able to determine the required size of the staybolts when the pressure is known.

Information: From the previous lesson you know the formula for finding the S.W.P. on a boiler. Let us now use this formula to develop a formula to find the minimum diameter of the staybolts needed for a given pressure.

$$P = \frac{a \times C}{A}$$

Substituting .7854 d^2 for "a",

$$P = \frac{.7854\ d^2 \times C}{A}$$

$$P \times A = .7854\ d^2 \times C$$

$$\frac{P \times A}{C} = .7854\ d^2$$

$$\frac{P \times A}{.7854C} = d^2$$

$$\sqrt{\frac{P \times A}{.7854C}} = d \quad \text{or} \quad d = \sqrt{\frac{P \times A}{.7854C}}$$

Example 1: Find the diameter of the staybolts needed if the pressure is 789 p.s.i., the pitch is 7" × 8" and the stress constant is 9000 p.s.i.

$$d = \sqrt{\frac{P \times A}{.7854C}}$$

$$= \sqrt{\frac{789 \times 7 \times 8}{.7854 \times 9000}}$$

$$= \sqrt{6.25}$$

$$= 2.5''$$

Example 2: Find the diameter of the staybolts needed if the S.W.P. is 240 p.s.i., the pitch is 5" × 5" and the stress constant is 9000 p.s.i.

$$d = \sqrt{\frac{P \times A}{.7854C}}$$

$$= \sqrt{\frac{240 \times 5 \times 5}{.7854 \times 9000}}$$

$$= \sqrt{.8488} = .92''$$

It is possible to find the square root of any number by arithmetic, but most people use a calculator. We will not go into the airhtmetic.

Reference: *A.S.M.E. Code*

Procedure: After studying the above information and the listed reference, answer the following.

Assignment:

1. Using the formula for S.W.P. on a staybolt, develop the formula for finding the required diameter of the staybolts.

2. The S.W.P. on the staybolts is 98 p.s.i., the stress constant is 8000 p.s.i., and the pitch is 4″ X 4″. Find the diameter of the staybolts required.

3. The S.W.P. on the staybolts is 89 p.s.i., the stress constant of the staybolt is 5000 p.s.i., and the pitch is 5″ X 5″. Find the diameter of the staybolts required.

4. Find the required diameter of the staybolts if the pressure is 200 p.s.i., the stress constant is 8500 p.s.i., and the pitch is 7″ X 8″.

5. Find the square root of the following, using a calculator.
   a. 2,116
   b. 78,961
   c. 148,996
   d. 538,756
   e. 954,529

Longitudinal and Circumferential Seams — Assignment 3-B-3

Objective: Be able to describe the types of seams that are used in the construction of steam boilers.

Be able to compare the efficiencies of seams that are used in the construction of steam boilers.

Information: Riveted construction of the longitudinal and circumferential seams in steam boilers consists of either a lap or a butt-strap type of seam. Seams can be single-, double-, or triple-riveted, depending upon the strength required. All lap seams are limited to boiler drums up to 36" in diameter and a maximum of 100 p.s.i. steam-carrying capacity.

On H.R.T. boilers with lap-seam construction, the boiler life is 20 years, as per the A.S.M.E. Code. With butt-strap construction there are not any limitations except for the strength of the joint itself. This of course is providing there is not any corrosion or caustic embrittlement present along the seam. The efficiencies of the various riveted joints are shown on sketch 3-B-3-1.

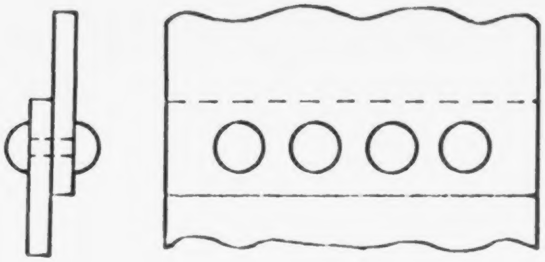
Steam boilers today are of welded construction and must conform with the A.S.M.E. Code. The welded seam (Sketch 3-B-3-2) is given a 100% efficiency rating provided the welding was done in a factory equipped to stress-relieve the metal, the joint is ground smooth, and the weld has been x-rayed for any imperfections. Welds that are done in the field are usually given an efficiency rating of 90%. Remember, all welding that is done on a steam boiler must be done by a certified welder and must conform to the specifications of the A.S.M.E. Code.

Reference: *Rules and Regulations* — Mechanical Inspection Bureau
A.S.M.E. Code
Steam Plant Operation
Elementary Steam Power Engineering

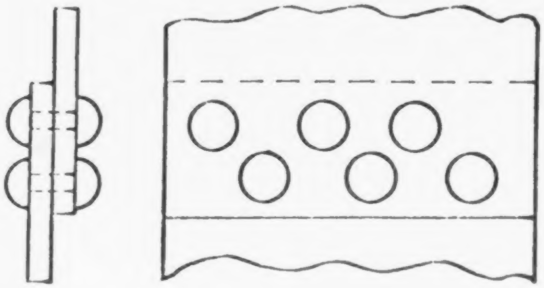
Procedure: After studying the listed references, answer the following questions and be prepared to discuss each question in class.

Assignment:

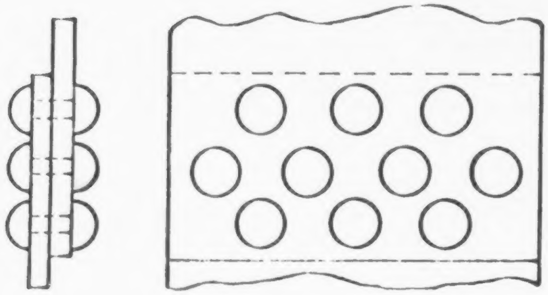
1. Sketch a lap and a butt-strap joint. What are their efficiencies?
2. Describe the advantages and disadvantage of three types of boiler-drum joints.



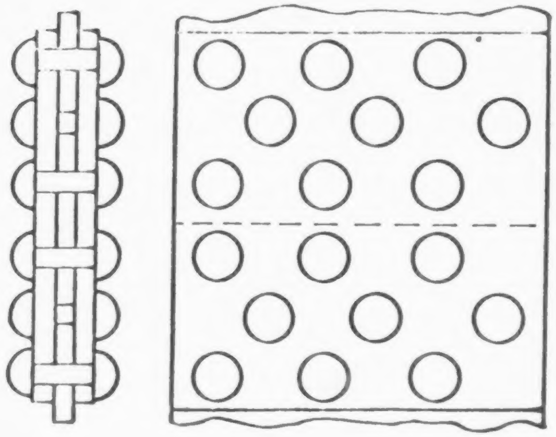
SINGLE-RIVETED
LAP SEAM 56% EFFICIENT



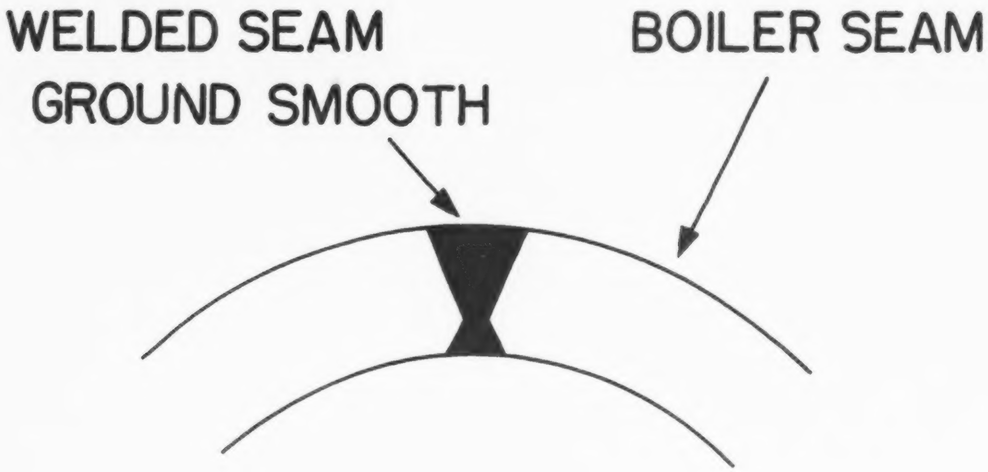
DOUBLE-RIVETED
LAP SEAM 70% EFFICIENT



TRIPLE-RIVETED
LAP SEAM 85% EFFICIENT



TRIPLE-RIVETED
DOUBLE BUTT-STRAP
SEAM 88% EFFICIENT


WELDED SEAM
GROUND SMOOTH
BOILER SEAM

WELDED SEAM DONE IN FACTORY 100% EFFICIENT
WELDED SEAM DONE IN FIELD 90% EFFICIENT

3-B-3-2

3. Several rivets have become loosened along the longitudinal seam:
    a. What would you do to overcome this condition?
    b. Where and how do you caulk a joint?
    c. What caused this condition?

4. If you were installing a new boiler in your plant, what kind of joint would you insist upon if the diameter of the shell was over 36"? Why?

5. What rules and regulations govern the construction of steam boilers?

6. Who enforces the rules and regulations in New Jersey?

Objective: Be able to determine the stress on the longitudinal and circumferential seams of a steam boiler.

Information: In lesson 3-B-1 we defined stress as a force tending to cause a break in a material divided by the area of the material that resists the break.

$$\text{Stress} = \frac{\text{Force (Tending to break)}}{\text{Area (Resisting break)}}$$

Let us now examine how this will apply to the **longitudinal** seams of the steam boiler.

The force tending to cause a rupture along a seam is equal to the pressure in the drum multiplied by the area it is acting on. This is shown in sketch 3-B-3-M1–1. If the seam has an efficiency of less than 100%, the break will occur at "A" or "B".

$$\text{Total force} = \text{Pressure} \times \text{area}$$

For practical purposes the area on which the pressure is acting may be taken as the projected area A B C D as shown in sketch 3-B-3-M1-2.

Then Area (A B C D) = Diameter times length of cylinder
T. F. = P X Area (A B C D)
or – T. F. = P X d X L

The area that is resisting a break consists of the two strips of metal as shown in sketch 3-B-3-M1-3. This area is therefore two times the product of the thickness and length of the cylinder.

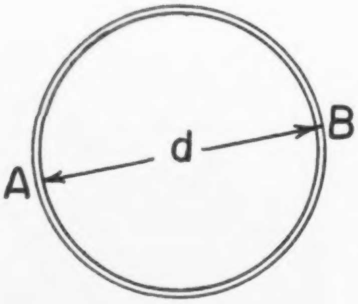
$$\text{Area} = 2 \times t \times L$$

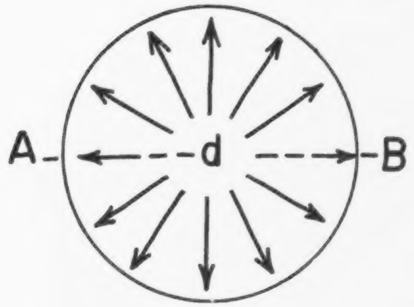
We can now write an equation for the stress on the longitudinal seams.

$$\text{Longitudinal stress} = \frac{\text{Total force}}{\text{Area}}$$

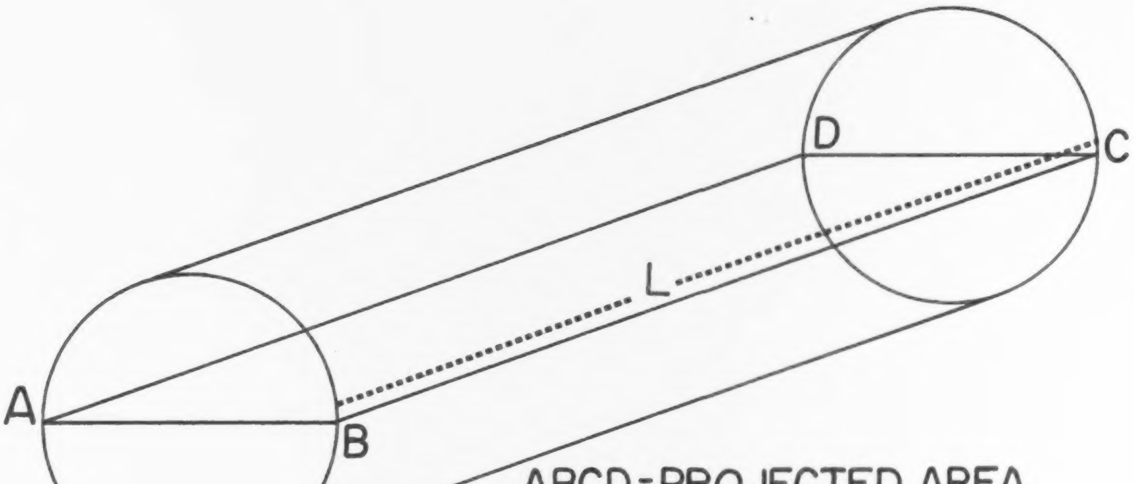
$$\text{Longitudinal stress} = \frac{\text{Pressure} \times \text{diameter} \times \text{length}}{2 \times \text{thickness} \times \text{length}}$$

$$\text{Longitudinal stress} = \frac{P \times d \times L}{2 \times t \times L}$$





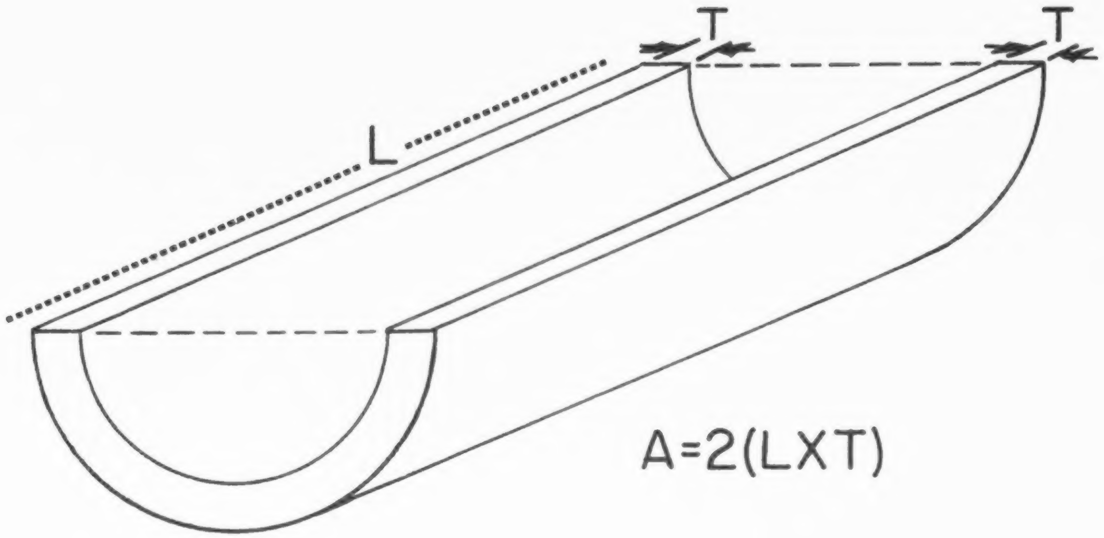
3-B-3-MI-1



ABCD = PROJECTED AREA OF STRESS

3-B-3-MI-2

STRESS ON LONGITUDINAL SEAMS



3-B-3-MI-3

AREA RESISTING A LONGITUDINAL BREAK

This can be reduced to

$$\text{Longitudinal stress} = \frac{P \times d}{2t}$$

This shows that the length of the cylinder does not affect the unit stress within the material.

Let us now examine the circumferential seams of a steam boiler. The force tending to cause a rupture along that seam is equal to the pressure in the drum multiplied by the area it is acting on – shown in sketch 3-B-3-M1-4. The break would occur across section A B (assuming that the efficiency is less than 100%).

Total force = Pressure X area

The area on which the pressure is acting is the head of the cylinder. The area of the cylinder head is:

$\text{Area} = .7854 \times d^2$
Total force = Pressure X area
T.F. = P X area of head
$\text{T.F.} = P \times .7854 \times d^2$

The area that is resisting the break is the section of material shown in sketch 3-B-3-M1-5. This area is the product of the circumference of the drum and the thickness of the material.

Area = Circumference X thickness

The circumference is equal to: $3.1416 \times d$

Then the area $= 3.1416 \times d \times t$

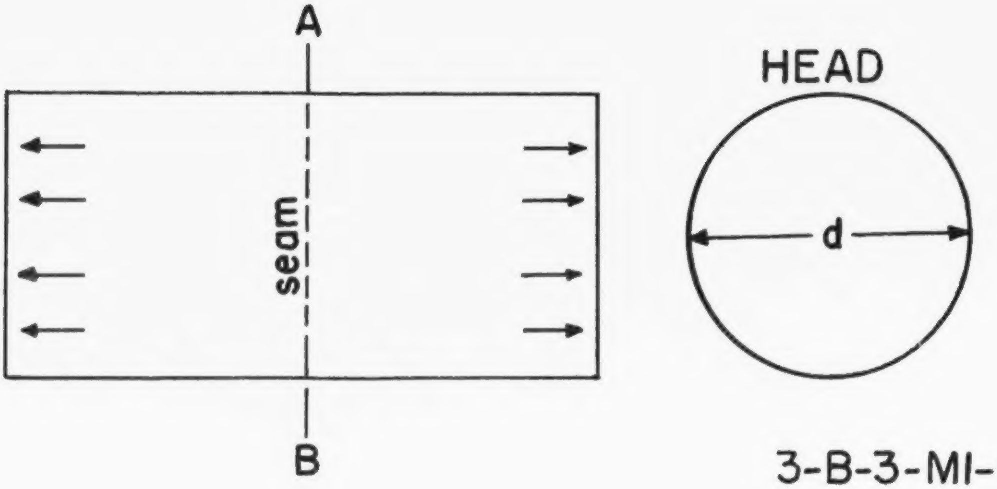
We can now write an equation for the stress on a circumferential seam.

$$\text{Circumferential stress} = \frac{\text{Total force}}{\text{Area}}$$

$$\text{Circumferential stress} = \frac{P \times .7854 \times d^2}{3.1416 \times d \times t}$$

Simplifying:

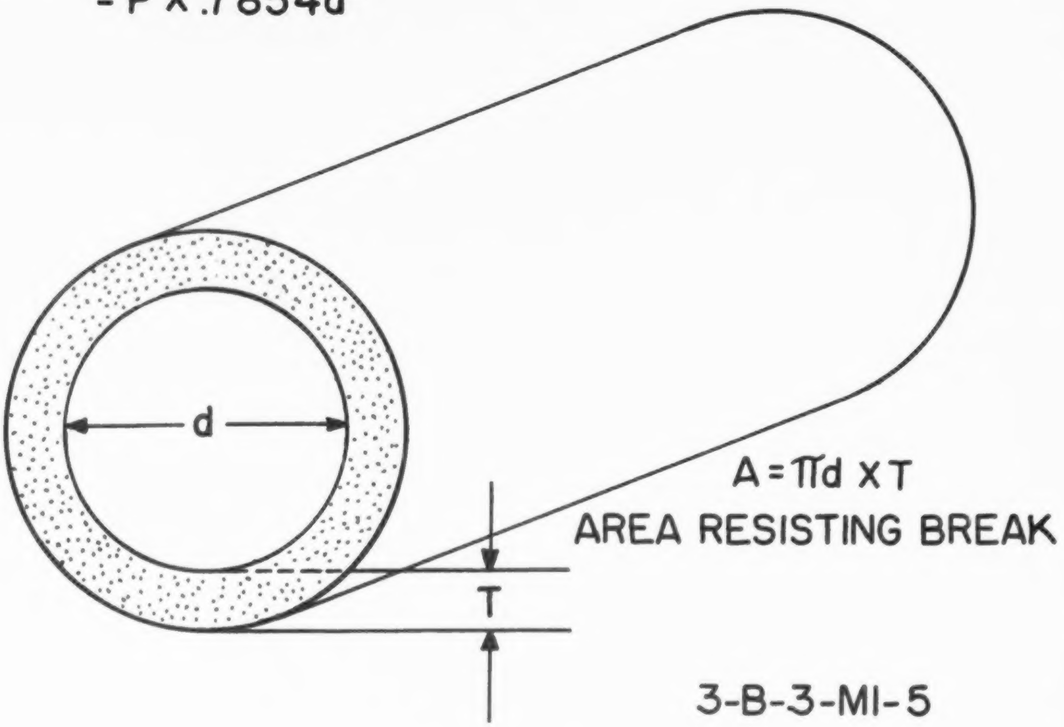
$$\text{Circumferential stress} = \frac{P \times d}{4t}$$


A
HEAD
seam
d
B

3-B-3-MI-4

FORCE = P X Area of head

= P X $.7854d^2$


d
$A = \pi d \times T$
AREA RESISTING BREAK
T

3-B-3-MI-5

STRESS ON CIRCUMFERENTIAL SEAM

You now have two equations to find the longitudinal and circumferential stresses on a boiler drum.

Example 1: Find the circumferential and longitudinal stresses on a boiler shell 36" in diameter, 12 feet long, with a plate thickness of ½" and a steam pressure of 175 p.s.i.

$$\text{Circumferential stress} = \frac{P \times d}{4t} = \frac{175 \times 36}{4 \times .5} = 3150 \text{ p.s.i.}$$

$$\text{Longitudinal stress} = \frac{P \times d}{2t} = \frac{175 \times 36}{2 \times .5} = 6300 \text{ p.s.i.}$$

Example 2: If you have a boiler with a pressure of 200 p.s.i., and the drum has a diameter of 40 inches, a thickness of ½" and a length of 12 feet, what would be the longitudinal and circumferential stresses on the seams?

$$\text{Circumferential stress} = \frac{P \times d}{4t} = \frac{200 \times 40}{4 \times .5} = 4000 \text{ p.s.i.}$$

$$\text{Longitudinal stress} = \frac{P \times d}{2t} = \frac{200 \times 40}{2 \times .5} = 8000 \text{ p.s.i.}$$

The stress on the longitudinal seam is two times as great as the stress on the circumferential seam. For this reason longitudinal seams are made to resist greater stress and are given even closer attention than circumferential seams.

Reference: *Steam Plant Operation*
Elementary Steam Power Engineering

Procedure: After studying the information and references, do the following problems.

Assignment:

1. Prove that the force on the longitudinal seam is twice as great as the force on the circumferential seam.
2. What must be the strongest seam on a boiler? Why?
3. A boiler has a pressure of 150 p.s.i., a drum diameter of 36", metal thickness of 5/8", and a length of 10 feet. Find the stress on the circumferential and longitudinal seams.
4. Find the circumferential and longitudinal stress on a boiler shell 48" in diameter, 12 feet long, with a plate thickness of 1", if the steam pressure is 400 p.s.i.

Safety Valves – Review of Basic Construction, Function, and Code Requirements

Assignment 4-A-1

Objective: Be able to state A.S.M.E. Code requirements regarding safety-valve relieving capacity.

Information: You should know from your second year's work (Units 4-A-1, 4-A-2, and 4-A-2-M1) the types, purpose, location, construction, and a few of the A.S.M.E. Code requirements for safety valves. Let's just hit a few of the highlights. All safety valves must be built according to the A.S.M.E. Code for the pressures and temperatures they will work at.

Boilers with over 500 sq. ft. of heating surface must have two or more safety valves. They must be located at the highest part of the steam side of the boiler, as close to the shell as possible, with no intervening valves. Safety valves over 3 inches in diameter for pressures over 15 p.s.i. shall have a flanged or a weld-end inlet; only spring-loaded pop-type safety valves are allowed. They must be designed to pop open fully without chattering and remain open until there is a definite drop in pressure. They should close at a pressure not lower than 96% of their set pressure. The minimum blowdown shall be 2 p.s.i., and for pressures between 100 and 300 p.s.i. inclusive, not less than 1% of the set pressure.

Popping-point tolerance, plus or minus, shall be as follows:

2 p.s.i. for pressures up to 70 p.s.i.
3% for pressures from 71 to 300 p.s.i.
10% for pressures over 300 to 1000 p.s.i.
1% for pressures over 1000 p.s.i.

References:
Steam Plant Operation
Elementary Steam Power Engineering
A.S.M.E. Code Section I
Stationary Engineering Science Manual 2

Procedure: After having read the information and listed references, answer the following questions and be prepared to discuss them in class.

Assignment:

1. How does the A.S.M.E. Code determine the minimum safety-valve relieving capacity?
2. What three methods are used to prove that the safety-valve relieving capacity is accurate?
3. Whom does the A.S.M.E. Code require to repair or replace safety-valve springs?
4. What stampings are required on safety valves?

Relieving Capacity of Safety Valves Based on Fuel Used

Assignment 4–A–1M1

Objective: Be able to determine the relieving capacity of the safety valves needed in reference to the amount and type of fuel burned.

Information: In order to determine the proper size of safety valve required for a boiler, one of the things we must know is the capacity of the boiler. The capacity is rated in pounds per hour of steam.

The A.S.M.E. Code states that, when the capacity in pounds per hour of a steam boiler is not known, it may be determined by the maximum amount of fuel that can be consumed by the burners on said boiler. It is to be determined using the following formula:

$$W = \frac{C \times H \times 0.75}{1100}$$

Where:
W = Pounds of steam per hour
C = Pounds or cubic feet of fuel per hour
H = Heating value of fuel per pound or cubic foot

You will note that the capacity found will be in pounds per hour. It will then be necessary for the safety-valve manufacturer to supply you with a valve or valves capable of relieving that capacity at the M.A.W.P. for your particular boiler.

Example 1: A burner has a maximum fuel rate of 900 pounds per hour, and the fuel has a heat content of 18,000 Btu per pound. How many pounds of steam per hour will this boiler produce?

$$W = \frac{C \times H \times 0.75}{1100}$$

$$= \frac{900 \times 18{,}000 \times 0.75}{1100}$$

$$= 11{,}045 \text{ lbs/hr}$$

Example 2: The gas burner on a boiler has a maximum firing rate of 50,000 cubic feet of gas per hour. If the heat content of the gas is 1050 Btu per cubic foot, what is the capacity of the boiler in pounds of steam per hour?

$$W = \frac{C \times H \times 0.75}{1100}$$

$$= \frac{50{,}000 \times 1050 \times 0.75}{1100}$$

$$= 35{,}795 \text{ lbs/hr}$$

Reference: *A.S.M.E. Code*

Procedure: After studying the above information and the reference, answer the following questions.

Assignment:

1. When is the maximum amount of fuel consumed per hour used to determine boiler steaming capacity?

2. What does each term in the formula $W = \frac{C \times H \times 0.75}{1100}$ represent?

3. A gas burner uses 75,000 cubic feet of gas per hour. The gas has a heat content of 1040 Btu per cubic foot. What is the maximum capacity of the boiler that this burner is attached to?

4. A stoker-fired boiler uses 5 tons of coal per hour. The coal has a heat content of 12,500 Btu per pound. What is the possible capacity of the boiler in pounds of steam per hour?

5. An oil-fired boiler uses 500 gallons of oil an hour. If the heat content of the oil is 142,000 Btu per gallon, what is the capacity of the boiler?

Relieving Capacity of Safety Valves Based on Area of Heating Surface

Assignment 4-A-1-M2

Objective: Be able to determine the capacity of a boiler, based on the amount of heating surface.

Information: The A.S.M.E. Code states that, when the capacity in pounds per hour of a steam boiler is not know, it may be determined by the number of square feet of heating surface in the boiler.

You will note that the capacity found will be in pounds per hour. It will then be necessary for the safety-valve manufacturer to supply you with a valve or valves capable of relieving that capacity at the M.A.W.P. for your particular boiler.

The following formulas are to be used:

For firetube boilers:

$$W = (8 \times H.S.)_B + (14 \times H.S.)_{WW}$$

For watertube boilers:

$$W = (10 \times H.S.)_B + (16 \times H.S.)_{WW}$$

Where:

W = Pounds of steam per hour
H.S. = Heating surface in square feet
B = Boiler (except waterwalls)
W.W.= Waterwalls in furnace

Example 1: A firetube boiler has 400 square feet of boiler heating surface and 80 square feet of waterwalls. What is the capacity of the boiler?

$$\begin{aligned} W &= (8 \times H.S.)_B + (14 \times H.S.)_{WW} \\ &= (8 \times 400)_B + (14 \times 80)_{WW} \\ &= 3200 + 1120 \\ &= 4320 \text{ pounds per hour} \end{aligned}$$

Example 2: A firetube boiler has 2200 square feet of boiler heating surface but is not equipped with waterwalls. Find the number of pounds of steam per hour that this boiler can produce.

$$\begin{aligned} W &= (8 \times H.S.)_B + (14 \times H.S.)_{WW} \\ &= (8 \times 2200)_B + (14 \times 0)_{WW} \\ &= 17{,}600 + 0 \\ &= 17{,}600 \text{ pounds per hour} \end{aligned}$$

Example 3: A watertube boiler contains a total heating surface of 5000 square feet; 800 square feet is waterwall heating surface. Find the capacity of the boiler.

$$\begin{aligned} W &= (10 \times \text{H.S.})_B + (16 \times \text{H.S.})_{WW} \\ &= (10 \times 4200) + (16 \times 800) \\ &= 42000 + 12800 \\ &= 54{,}800 \text{ pounds per hour} \end{aligned}$$

Reference: *A.S.M.E.Code*

Procedure: After studying the above and the reference, do the following problems.

Assignment:

1. What is the capacity of a firetube boiler with 1250 square feet of boiler heating surface and 200 square feet of waterwalls?

2. Find the capacity of a firetube boiler without waterwalls that has 1750 square feet of heating surface.

3. A watertube boiler contains 6250 square feet of heating surface and also 1050 square feet of waterwall. Find the number of pounds of steam per hour that this boiler is capable of producing.

4. When is the heating surface of a boiler used to determine boiler capacity?

Objective: Be able to determine the size of the safety valves needed for a given capacity of steam in pounds per hour.

Information: From the last two lessons you learned how to figure the capacity of a boiler based on either the fuel used or the amount of heating surface of the boiler. The value thus determined may be used to find the approximate area of the safety valves needed on that boiler.

The area needed will equal 0.2 times the number of pounds of steam per hour divided by the M.A.W.P. of the boiler plus ten, or

$$\text{Area} = \frac{.2W}{P + 10}$$

W = Pounds of steam per hour

P = Maximum allowable working pressure

Example 1: If a steam boiler can generate 11,045 pounds of steam per hour at a pressure of 200 p.s.i., what must be the area of the safety valves?

$$A = \frac{.2W}{P + 10}$$

$$= \frac{.2 \times 11{,}045}{200 + 10}$$

$$= 10.52 \text{ square inches}$$

Example 2: A watertube boiler can generate a maximum of 35,795 pounds of steam per hour at 300 p.s.i. What safety-valve area is needed to relieve that quantity of steam?

$$A = \frac{.2W}{P + 10}$$

$$= \frac{.2 \times 35{,}795}{300 + 10}$$

$$= 23.1 \text{ square inches}$$

After the area is found, it is possible to determine the diameter of the valve or valves needed.

$$\text{Area} = .7854 \times d^2$$

$$\frac{A}{.7854} = d^2$$

$$\sqrt{\frac{A}{.7854}} = d \qquad \text{or} \qquad d = \sqrt{\frac{A}{.7854}}$$

For the first and second examples it follows that:

1. $d = \sqrt{\frac{A}{.7854}} = \sqrt{\frac{10.52}{.7854}} = 3.66$ inches

Boiler #1 would need a valve of 3.66 inches or, as would be more likely, two valves of 2.6 inches each, to conform with the A.S.M.E. Code.

2. $d = \sqrt{\frac{A}{.7854}} = \sqrt{\frac{23.1}{.7854}} = 5.43$ inches

Boiler #2 would need a valve 5.43" in diameter. From the A.S.M.E. Code we see that instead it could have three safety valves, each 3.13 inches in diameter, to get the same area.

Reference: *Steam Plant Operation*
A.S.M.E. Code, Sections I and VII

Procedure: After studying the above and the listed references, answer the following questions.

Assignment:

1. What is the formula for finding the area of a safety valve needed to relieve a given capacity?
2. Explain each term in the formula.
3. Find the area needed to relieve a capacity of 30,000 pounds of steam per hour at a pressure of 120 p.s.i.
4. Find the area needed to relieve 80,000 pounds per hour at a pressure of 450 p.s.i.
5. If 4 valves of equal size were used in problem 3, what diameter would they have to be?
6. If 4 valves of equal size were used in problem 4, what diameter would they have to be?

Bottom Blowdown Valves — Review of Code Requirements and Waterwall Blowdowns

Assignment 4-B-1

Objective: Be able to state the A.S.M.E. Code requirements regarding bottom blowdown valves.

Be able to handle waterwall blowdown valves.

Information: All boilers shall have a blowoff pipe fitted with a valve or cock located at the lowest part of the water side of the boiler. When the M.A.W.P. exceeds 125 p.s.i., the blowoff pipe shall be at least extra heavy from the boiler to the valve or valves. It must run full size, with no reducers or bushings.

All fittings between the boiler and valve shall be steel or extra-heavy bronze or brass, malleable iron, or cast iron suitable for the temperatures and pressures involved.

When the M.A.W.P. exceeds 125 p.s.i., each bottom blowoff pipe shall be fitted with at least a 250-pound standard valve or cock, and preferably two valves or a valve and cock, both of which shall be extra heavy.

When the bottom blowoff pipe is exposed to direct furnace heat, it must be protected by firebrick, arranged so the pipe can be inspected. The opening in the boiler setting for the blowoff pipe should be arranged to provide for free expansion and contraction.

The minimum size for pipes and fitting is 1", the maximum 2½", including surface blowoff pipes.

Waterwall blowoff valves shall be locked or sealed closed to avoid being opened by mistake when boiler is firing. They should only be blown down when the firebox has had a chance to cool down. They are usually blown down when the boiler is being taken off the line.

The frequency of blowing down will be decided through feedwater analysis, but in any event a boiler should be blown down at least once every 24 hours.

Reference: *Steam Plant Operation*
Elementary Steam Plant Engineering
A.S.M.E. Code, Section I and VII

Procedure: After reading the information and studying the listed references, answer the following questions and be prepared to discuss them in class.

Assignment:

1. What types of piping and valves and fittings are required when the M.A.W.P. exceeds 125 p.s.i.?
2. How is the blowoff pipe protected from direct furnace heat?
3. What are minimum and maximum sizes of pipes for blowoff lines?
4. Why are waterwall blowoff valves locked closed?
5. When is best time to blow down waterwalls?

Objective: Be able to sketch and explain a steam-to-water cycle in a generating plant.

Information: A process plant that also generates its own electrical power has quite a complex steam-to-water cycle. Let us for our discussion consider a process plant with a turbogenerator that has two extraction stages and is operating condensing.

Starting at the boiler, the water is changed into steam and passes through the superheater, absorbing more heat. From the superheater it enters the steam header and divides into branches that go to the turbine throttle valve, steam auxiliaries, and the pressure-reducing desuperheating stations.

The steam that enters the turbine to generate electricity can be extracted for process at two pressure stages. Condensate from the steam that is used for process is returned to the open feed-water heater by a condensate pump. The steam that is not extracted for process is condensed in the condenser and falls into the hot well. The condenser's condensate pump removes the water from the hot well and discharges it through the first- and second-stage air-ejector condensers. It then travels back to the open feed-water heater.

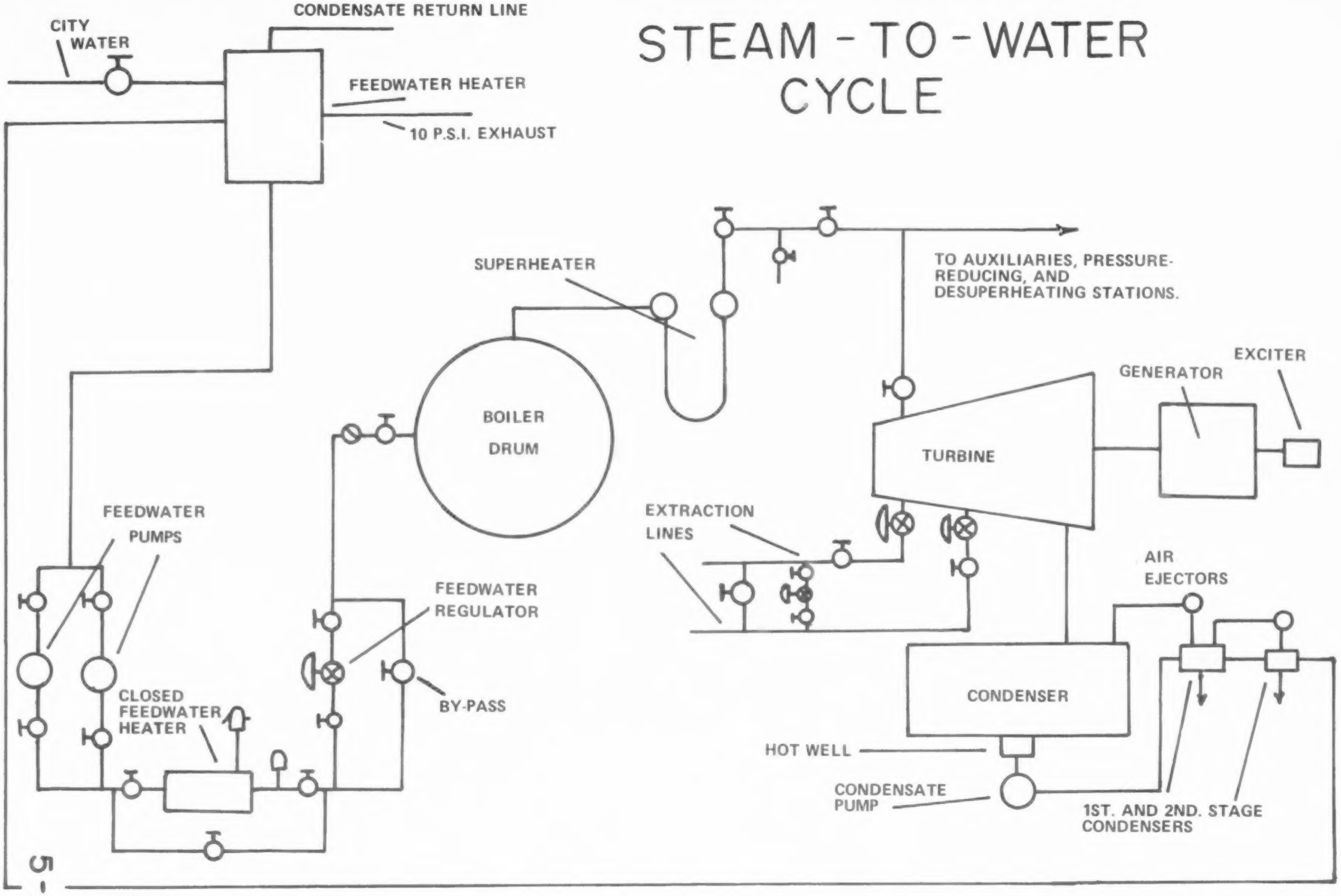
The exhaust steam from the auxiliaries is used in a low-pressure steam line for space heating, water heating, or in the open feed-water heater. The pressure-reducing and desuperheating station is used to balance the demand for process steam against the electric load on the turbogenerator.

All condensate is returned to the open feed-water heater. In the event there is a loss of condensate, a makeup valve opens to take care of the loss. The feed-water pump removes the water from the open feed-water heater and discharges it through the closed feed-water heater, where it is heated by extracted steam. The water is then regulated by the feedwater regulator on entering the boiler, before it passes through the feed-water check and stop.

Reference: *Steam Plant Operation*
Elementary Steam Power Engineering

Procedure: After studying the above information and the listed references, do the following assignment and be prepared to discuss it in class.

STEAM - TO - WATER CYCLE


CITY WATER
CONDENSATE RETURN LINE
FEEDWATER HEATER
10 P.S.I. EXHAUST
SUPERHEATER
TO AUXILIARIES, PRESSURE-REDUCING, AND DESUPERHEATING STATIONS.
BOILER DRUM
GENERATOR
EXCITER
TURBINE
EXTRACTION LINES
FEEDWATER PUMPS
FEEDWATER REGULATOR
CLOSED FEEDWATER HEATER
BY-PASS
AIR EJECTORS
CONDENSER
HOT WELL
CONDENSATE PUMP
1ST. AND 2ND. STAGE CONDENSERS

5-A-1-1

85

Assignment:

1. Why is it important to know the steam-to-water cycle?

2. Sketch a steam-to-water cycle of a single-extraction turbogenerator.

3. Using your sketch, explain the cycle, starting at the open feedwater heater.

Feed-Water Economizer

Assignment 5-B-1

Objective: Be able to state the factors that determine the use of a feedwater economizer.

Information: Feedwater economizers are located between the last pass of a boiler and the breeching. The feed water thus reclaims some of the heat from the combustion gases before they pass into the stack.

When a feedwater economizer is used, there is . . .

1. A saving in fuel of 7 to 20 percent. A rule of thumb is a 1 percent saving for every 10°F. rise in feedwater temperature.
2. A loss in overall economy when there is poor chimney draft or when the boiler is run at low loads.
3. A gain in economy when boilers use forced or induced draft.
4. Decreased wear and tear on boilers due to high feed-water temperature.
5. Less themal shock to boiler metals.

Other factors that suggest the use of an economizer:

1. The temperature of the flue gas: The higher the temperature, the greater the thermal savings.
2. On boilers that operate at 400 p.s.i. or higher, an economizer is a necessity.
3. With electrically driven auxiliaries, exhaust steam is not available for feedwater heating.

Economizer surface costs less to construct than boiler heating surface. Hence the tendency in modern high-pressure boilers is to decrease boiler heating surface to a minimum and install large economizers.

References: *Steam Power Plant Engineering*
Steam Plant Operations
Elementary Steam Power Engineering
Practical Heat

Procedure: After studying the above information and the listed references, complete the following assignment.

Assignment:

1. What is a feed-water economizer?
2. Where is it located?
3. What are the temperatures of the flue gases leaving the boiler, and what are they reduced to when using and economizer?
4. What is the average temperature of feed water entering and leaving the economizer?
5. Why is it necessary to use an induced-draft fan with an economizer?
6. a. What is meant by a parallel-flow economizer?
   b. What is meant by a counterflow economizer?
   c. Which is considered more efficient?
7. What are the tube sizes used in an economizer?
8. Indicate the typical heat balance in a modern power plant:
   a. Boiler efficiency
   b. Boiler efficiency with economizer
   c. Boiler efficiency with economizer and air preheater.

Objective: Be able to explain how a two-element feed-water regulator operates.

Information: We have discussed feed-water regulators that start and stop a feed-water pump or open and close a solenoid valve (Example: McDonald Miller). We have also talked about the thermostatic expansion-tube-type feed-water regulator (Example: Copes). Another common type on medium-sized boilers is the thermo-hydraulic feed-water regulator (Example: Reiley). These feed-water regulators have one thing in common: they work on a drop or rise in the boiler's water level.

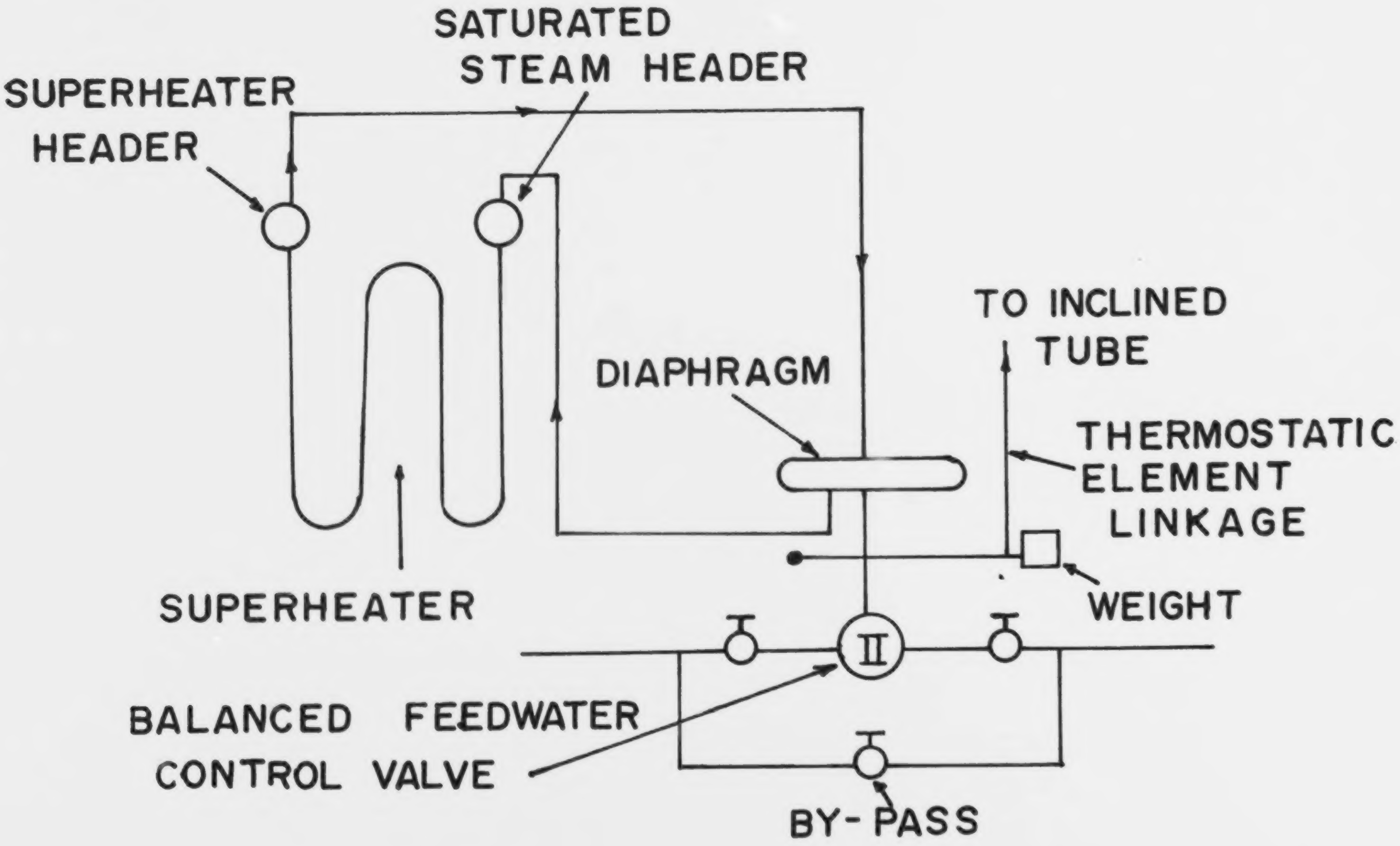
The two-element feed-water regulator is found on medium to large boilers that are subject to sudden load changes, such as would be found in a process plant. They are controlled by two elements: one is the rise and fall of the water level in the boiler – which you are quite familiar with. The other is the steam-flow from the boiler, measured by taking the difference in pressure across the superheater. This pressure difference is applied across a diaphragm and gives motion to a valve mechanism on the feed-water regulator.

Reference: *Steam Plant Operation*
Elementary Steam Power Engineering

Procedure: After studying the above information and the listed references, answer the following questions.

Assignment:

1. What are the two elements used to control the water level in a boiler?
2. Why is it desirable to use a two-element type of regulator?
3. Describe the operation of a two-element regulator.
4. How can control lines be checked for leakage?
5. What maintenance schedule is recommended?


SATURATED STEAM HEADER
SUPERHEATER HEADER
TO INCLINED TUBE
DIAPHRAGM
THERMOSTATIC ELEMENT LINKAGE
SUPERHEATER
WEIGHT
II
BALANCED FEEDWATER CONTROL VALVE
BY-PASS

TWO-ELEMENT FEEDWATER REGULATOR

Objective: Be able to determine the water horsepower and the drive horsepower for a centrifugal pump.

Information: Before we can start to find the horsepower of a centrifugal pump we will first have to review some of the facts from previous lessons.

Total head against which a pump has to operate is equal to

$$\text{Discharge head} + \text{friction head} \pm \begin{matrix}\text{suction lift}\\ \text{or}\\ \text{suction head}\end{matrix}$$

To convert pounds per square inch into foot head, you divide the p.s.i. by .433. There are .433 p.s.i. per vertical foot.

To find the **water horsepower** of a centrifugal pump you can use the formula for mechanical horsepower:

$$HP = \frac{\text{foot pounds/min}}{33{,}000 \text{ ft. lb./min}}$$

Example 1: A centrifugal pump delivers 1000 gallons of water per minute against a head of 120 ft. Determine the water horsepower (neglect frictional loss).

$$HP = \frac{\text{ft. lbs.}}{33{,}000}$$

There are 8.33 pounds of water in a gallon.

$$HP = \frac{1000 \times 8.33 \times 120}{33{,}000} = 30.29$$

This is the water HP. To find the **HP needed to drive the pump,** you have to take the efficiency of the drive into consideration.

$$HP_{drive} = \frac{HP_{developed}}{\text{Efficiency}}$$

Assuming an efficiency of 75%, you have:

$$HP_{drive} = \frac{HP_w}{\text{Eff}} = \frac{30.29}{.75} = 40.39$$

Example 2: Find the HP required to feed 600 gallons of water per hour to a boiler operating at 112 p.s.i. (ignore friction .)

$$HP_w = \frac{\text{ft. lbs.}}{33{,}000}$$

You must change gallons per hour into gallons per minute. You must also change p.s.i. to foot head by dividing by .433.

$$HP_w = \frac{600 \times 8.33 \times 112}{60 \times 33{,}000 \times .433} = .65 \text{ (water horsepower)}$$

Assuming an efficiency of 75%, you have:

$$HP_d = \frac{HP_w}{Eff} = \frac{.65}{.75} = .87 \text{ (drive horsepower)}$$

Reference: *Steam Plant Operation*

Procedure: After studying the information and reference, do the following problems.

Assignment:

1. A pump delivers 2500 pounds of water per minute to a tank 100 feet above the pump. How much drive horsepower is required? (Assume there is no loss due to friction.)

2. What horsepower is required to deliver 2500 gallons of water per minute to a height of 300 feet if the pump is 75% efficient?

3. What is the horsepower of a boiler feed pump that delivers 30,000 pounds of water per hour against a pressure of 200 p.s.i. The pumping unit is 80% efficient.

4. Determine the horsepower needed to operate a pump that is feeding water to a boiler at the rate of 80,000 pounds per hour against a pressure of 415 p.s.i. Assume a pump efficiency of 75%.

5. A condensate pump on a surface condenser operates with a 29" vacuum suction and a 100 ft. head discharge. It pumps 70,000 lbs. of water per hour. If the unit is 80% efficient, how much HP is required to drive this unit? (See Second-Year Manual to figure total foot head)

Objective: Be able to state why the velocity of a fluid in piping must be limited.

Be able to state and explain the formula for the velocity of a fluid in a pipeline.

Information: The piping system of any plant is an essential part of the overall operation. We know that piping must be able to withstand the pressures and temperatures involved. In addition the velocity of the fluid in the line must be carefully controlled.

The velocity of water in pipelines must not be over 500 feet per minute. Saturated steam lines are limited to a flow of 6000 feet per minute. There are some exceptions: velocity in the suction line to a water pump is limited to 250 feet per minute; superheated steam supplied to turbines may have line velocities up to 12,000 feet per minute.

When the velocity in pipelines is within the proper design limits, the pressure-drop through the line will be kept within the necessary limits.

We can find the velocity in a line through which a fluid is moving by using the following formula:

$$\text{Velocity in a line} = \frac{\text{Quantity of fluid}}{\text{Area of line}}$$

This formula will be used in your next unit of study.

Let us now review the velocity limits given above:

Water lines	–	500 feet per minute
Pump discharge	–	500 " " "
Pump suction	–	250 " " "
Saturated steam	–	6,000 " " "
Superheated steam	–	12,000 " " "

It is of course much more desirable to have low velocities in lines. To reduce velocity you need larger pipes, and this of course means higher costs. So the need to keep costs down tends to keep pipe sizes down and velocities near their maximum safe limit.

Reference: *Steam Plant Operation*

Procedure: After studying the information and the listed reference, answer the following questions and be prepared to discuss each in class.

Assignment:

1. Why are there limits on fluid velocities in pipelines?
2. Why is there a difference in allowable velocity between saturated and superheated steam?
3. Can you explain the reason for the difference between the suction and discharge velocities of a water pump?
4. What is the formula for finding the velocity in a pipeline? Explain each term.
5. Set up a table for velocity limits in lines for fluids.

Objective: Be able to determine the sizes of pipes needed to hold the velocity of fluids within given limits.

Information: The basic formula for finding the velocity of a fluid in a pipeline is:

$$\text{Velocity} = \frac{\text{Quantity}}{\text{Area}}$$

$$V = \frac{Q}{A}$$

Where: V = Velocity of fluid in feet per minute.
Q = Quantity of fluid in cubic feet per minute.
A = Area of a cross section of the pipe in square feet.

In steam plants, the flow or quantity of steam going through a line is measured in pounds per hour rather than in cubic feet per minute. It is therefore necessary to change the pounds per hour into cubic feet per minute. We use the following formula:

Quantity = Pounds of steam per min. X specific volume

$$Q = W \times S.Vol.$$

Where: Q = Quantity in cubic feet per minute
W = Pounds of steam per minute
S.Vol. = Specific volume of steam determined from steam table relating pressure and temperature. Specific volume is given in cubic feet per pound.

It is now possible for us to substitute values as follows:

$$\text{Velocity} = \frac{\text{Quantity}}{\text{Area}} = \frac{\text{lb./min. X Specific Volume}}{\text{Area}}$$

$$V = \frac{Q}{A} = \frac{W \times S.Vol}{A}$$

Example 1: 10,000 pounds of steam per hour is flowing through a pipeline at 5000 feet per minute. The steam has a specific volume of 2.5 cubic feet per pound. Determine the diameter of the pipeline.

$$V = \frac{Q}{A}$$

We will find the area of the pipeline first. We must transpose the formula.

$$A = \frac{Q}{V} = \frac{W \times S.Vol}{V}$$

Substituting, $$A = \frac{\frac{10,000}{60 \times 2.5}}{5,000}$$

$$A = \frac{10,000}{24} \times \frac{1}{5000}$$

$$A = \frac{1}{12} \text{ Square Foot}$$

Changing to square inches,

$$A = \frac{1}{12} \times 144 = 12 \text{ sq. in.}$$

From this we can now find the diameter of the pipe in inches.

$$A = .7854d^2$$

Or $$d = \sqrt{\frac{A}{.7854}}$$

$$d = \sqrt{\frac{12}{.7854}}$$

$$d = \sqrt{15.28}$$

$$d = 3.91 \text{ inches}$$

When it is water that is moving through a line, we measure flow in gallons per minute. This can be converted to cubic feet per minute by the following.

$$Q \text{ in cu. ft./min.} = \frac{\text{Gallons/min.}}{\text{7.5 gallons/cu. ft.}} = \frac{G.P.M.}{7.5}$$

Example 2: 40 gallons of water per minute is flowing through a suction line to a pump. The velocity of this water is 200 feet per minute. Determine the size of the suction line.

$$V = \frac{Q}{A}$$

Transposing, $A = \frac{Q}{V}$

$$A = \frac{\frac{G.P.M.}{7.5}}{V}$$

$$A = \frac{\frac{40}{7.5}}{200}$$

$$A = .0267 \text{ square feet}$$

Changing to square inches,

$$A = .0267 \times 144$$
$$A = 3.84 \text{ sq. in.}$$

$$A = .7854d^2 \quad \text{or} \quad d = \sqrt{\frac{A}{.7854}}$$

$$d = \sqrt{\frac{3.84}{.7854}}$$

$$d = 2.21 \text{ inches}$$

Example 3: From example 2, determine the size of the discharge line if the velocity in the line is 400 feet per minute.

$$A = \frac{Q}{V} = \frac{\frac{G.P.M.}{7.5}}{V}$$

$$A = \frac{\frac{40}{7.5}}{400}$$

$$A = .0133 \text{ sq. ft.}$$

$$\text{Or} \quad A = .0133 \times 144$$

$$A = 1.92 \text{ sq. in.}$$

$$d = \sqrt{\frac{A}{.7854}}$$

$$d = \sqrt{\frac{1.92}{.7854}}$$

$$d = 1.56 \text{ inches}$$

Reference: *Steam Plant Operation*

Procedure: After studying the information and reference, do the following problems.

Assignment:

1. What size steam header is needed on a saturated-steam boiler that carries 200 p.s.i. pressure and generates 60,000 pounds of steam per hour? The velocity in the header must not exceed 5000 feet per minute.

2. 10,000 pounds of steam per hour with a pressure of 200 p.s.i. is flowing through a 4" line. What is the velocity of the steam?

3. 60,000 pounds of steam per hour is flowing at a rate of 6000 ft.-min. It has a specific volume of 1.1 cu. ft. per pound. What is the size of the line?

4. A boiler feedwater pump is feeding 25,000 pounds of water to the boiler per hour. The suction-line velocity is 200 feet per minute. What is the size of the suction line?

   Note: Water weighs 62.4 lbs. per cu. ft.

5. What is the size of the discharge line in problem 4 if the discharge velocity is 400 feet per minute?

Objective: Be able to describe the purpose and function of pilot-operated pneumatic valves.

Information: You already know that valves are used to control the flow of a liquid or a gas. There are many types for specific services. As our power plants became larger our controls became more complicated.

The pilot-operated pneumatic valve is often used because it requires only a small change in the controlled pressure to get a full-range change of the regulator.

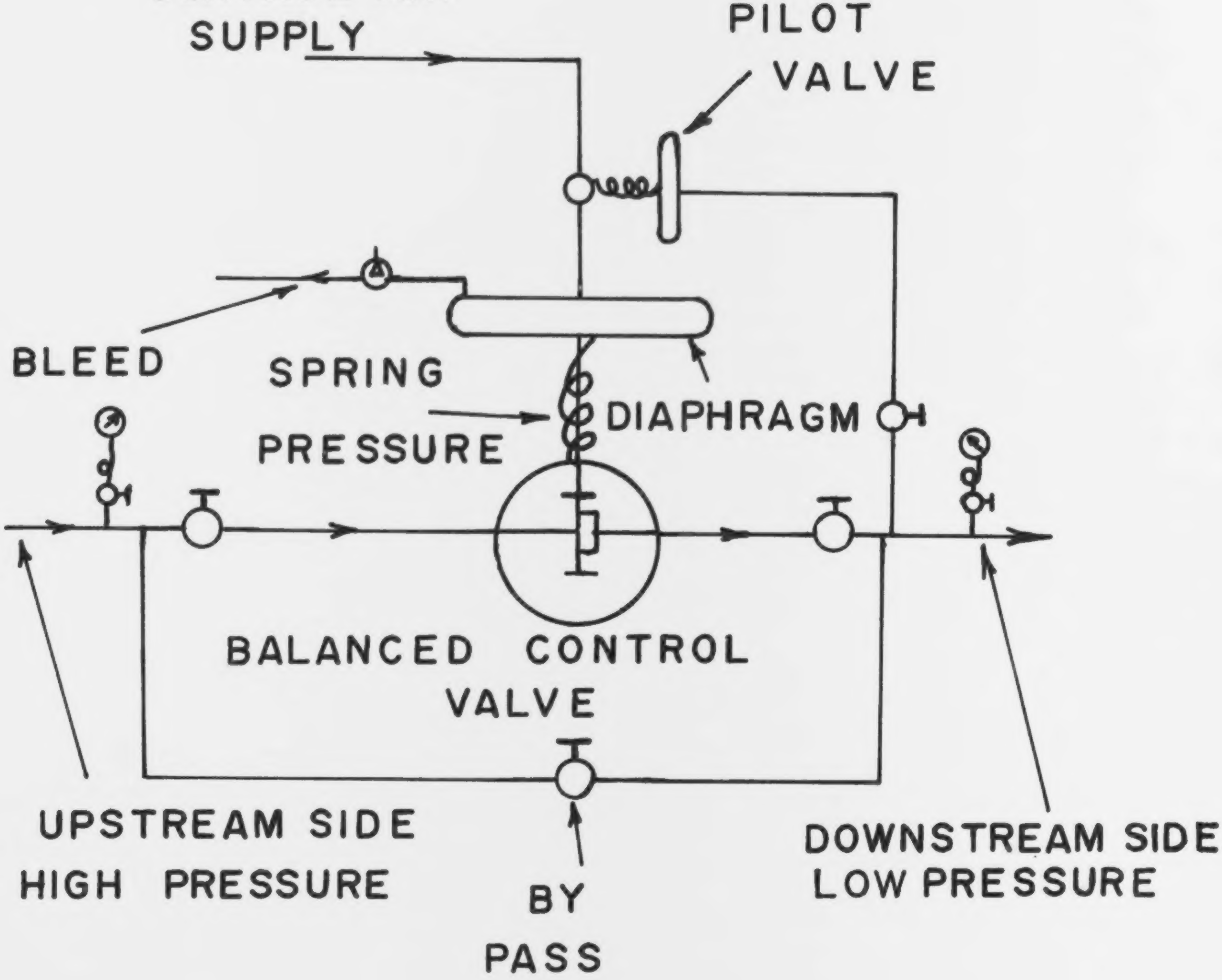
These valves should be equipped with stop valves and a bypass for emergency operation. They can be either pressure-opening or pressure-closing, depending on the application required.

Reference: *Instrumentation*
Manufacturers' catalogs

Procedure: After reading the information and references, answer the following questions and be prepared to discuss each in class.

Assignment:

1. Discuss the four elements needed for a control system.
2. What is a controller called when these four elements are found in one device?
3. On a pilot-operated pressure-regulating valve, what is the function of the pilot and how does it work?


CONTROL AIR SUPPLY
PILOT VALVE
BLEED
SPRING PRESSURE
DIAPHRAGM
BALANCED CONTROL VALVE
UPSTREAM SIDE HIGH PRESSURE
BY PASS
DOWNSTREAM SIDE LOW PRESSURE

PILOT-OPERATED PNEUMATIC VALVE

Objective: Be able to state the purpose of a heat exchanger.

Be able to classify heat exchangers and describe their basic construction.

Information: The purpose of a heat exchanger is to transfer heat from one fluid (liquid or gas) to another fluid. A heat exchanger can be used to

1. heat one liquid
2. reduce the temperature of a fluid
3. boil a fluid
4. condense steam

Regardless of which application is being used, it should be remembered that, in order to work, there must be a difference in temperature. Heat always travels from the hotter to the cooler liquid. In order to better understand heat exchangers, we must know more about their construction and classification.

Classification of heat exchangers

Heat exchangers are classified according to:

1. Direction of flow
2. Number of passes
3. Path of heat
4. Construction features

Direction of flow

1. Parallel flow. Both fluids flow in the same direction. When the object is to convert a vapor to a liquid at the same temperature, this type of exchanger is used. The two fluids leave the heat exchanger at almost the same temperature. The exchanger removes only the latent heat of evaporation. (Fig. 6-C-1-1)

2. Counterflow. The fluids flow in opposite directions. This type of exchanger is used when maximum temperature of heated fluid is desired. The cooler fluid leaves the heat exchanger at a temperature close to the inlet temperature of the hotter fluid. (Fig. 6-C-1-2)

3. Crossflow. One fluid flows perpendicular to second. Large volumes of vapor may be condensed by this type of flow (as in a surface condenser). (Fig. 6-C-1-3)

Number of passes

1. Single pass — where each fluid passes only once.
2. Multi-pass — where fluid, by use of baffles, makes two or three passes

Path of heat:

1. Indirect contact — permits no contact between fluids, as in a closed feed-water heater.
2. Direct contact — the two fluids are mixed together, as in an open feed-water heater.

General construction:

1. Shell and tube. This is a common construction where fluids do not come in direct contact. These are further classified as:
    a. Straight tube
    b. U-tube
    c. Multicoil
    d. Film type

2. Jet or mixer type. These are constructed so that both fluids enter and mix together, leaving the exchanger as a single fluid. Either the hotter fluid or the cooler fluid may pass into the shell through jets. The deaerating feed-water heater is a good example of this.

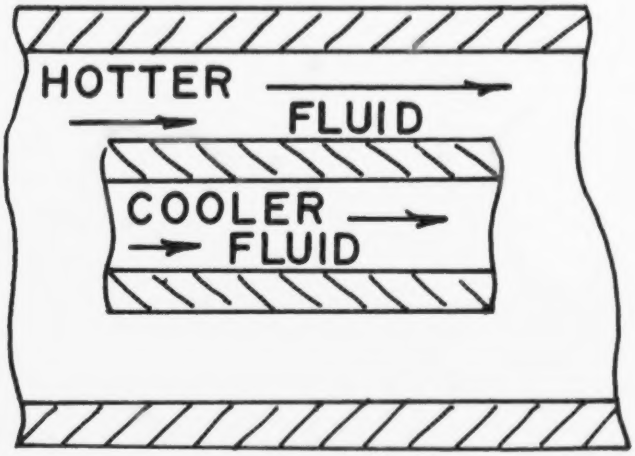
References: *Steam Plant Operation*
Elementary Steam Power Engineering

Procedure: After reading the information and studying the listed references, answer the following questions and be prepared to discuss each in class.

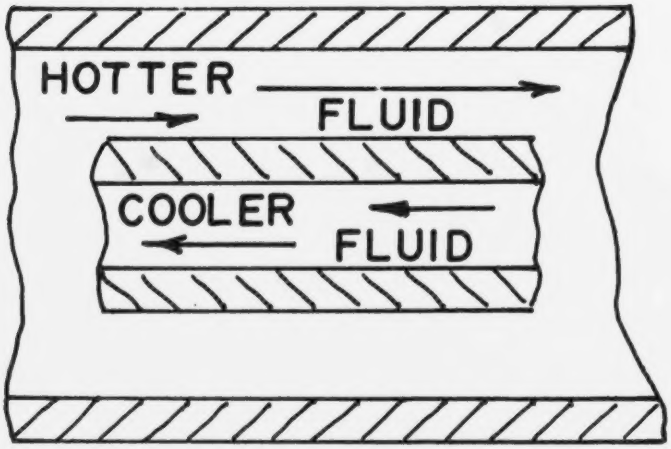
Assignment:

1. a) What is a heat exchanger?
    b) List four uses of a heat exchanger.

2. In what direction does heat always flow?


HOTTER
FLUID
COOLER
FLUID

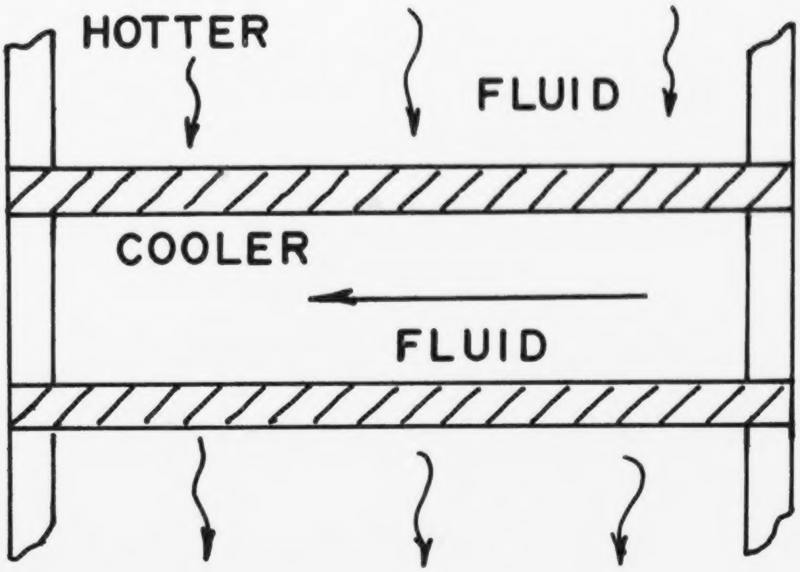
PARALLEL FLOW 6-C-1-1


HOTTER
FLUID
COOLER
FLUID

COUNTERFLOW

6-C-1-2

HEAT EXCHANGERS


HOTTER
FLUID
COOLER
FLUID

CROSSFLOW
HEAT EXCHANGER

6-C-1-3

3. How are heat exchangers classified?

4. a) Show by sketch
    - (1) Parallel flow
    - (2) Counterflow
    - (3) Crossflow

   b) Which of the above three would you pick for a fuel-oil heater?

5. What is meant by
   - a) A single-pass heat exchanger
   - b) A multi-pass heat exchanger

6. a) What is an indirect-contact heat exchanger?
   b) Give an example of one.

7. a) What is a direct-contact heat exchanger?
   b) Give an example of one.

8. List all the heat exchangers in our boiler room (at least seven).

Objective: Be able to describe chain (traveling-grate) stokers and tell how they work.

Information: Because of the inefficiency of hand-firing and the limits to the size of boilers because of hand-firing, some form of mechanical feeding had to be devised. The never-ending search for devices to save work gave birth to the stoker.

These stokers are classified according to the method used to introduce fuel into the furance, such as chain-grate, side-feed, underfeed, spreader, and over-feed.

The chain-grate stoker uses a chain that runs around two sprockets, one of which is attached to a variable-speed drive. Coal is deposited on the front of the grate and travels past an ignition arch that starts the combustion process. Air is fed through wind boxes under the grates and in sufficient quantities to complete combustion of the coal before the end of the grate is reached. Ash with a minimum amount of unburned fuel falls off the grate into the ash pit.

The amount of coal that is burned on this stoker depends upon the thickness of the fuel bed, the rate of grate travel, and the amount of air supplied.

The coals best suited for the chain-grate stoker are non-caking coals with relatively high ash content.

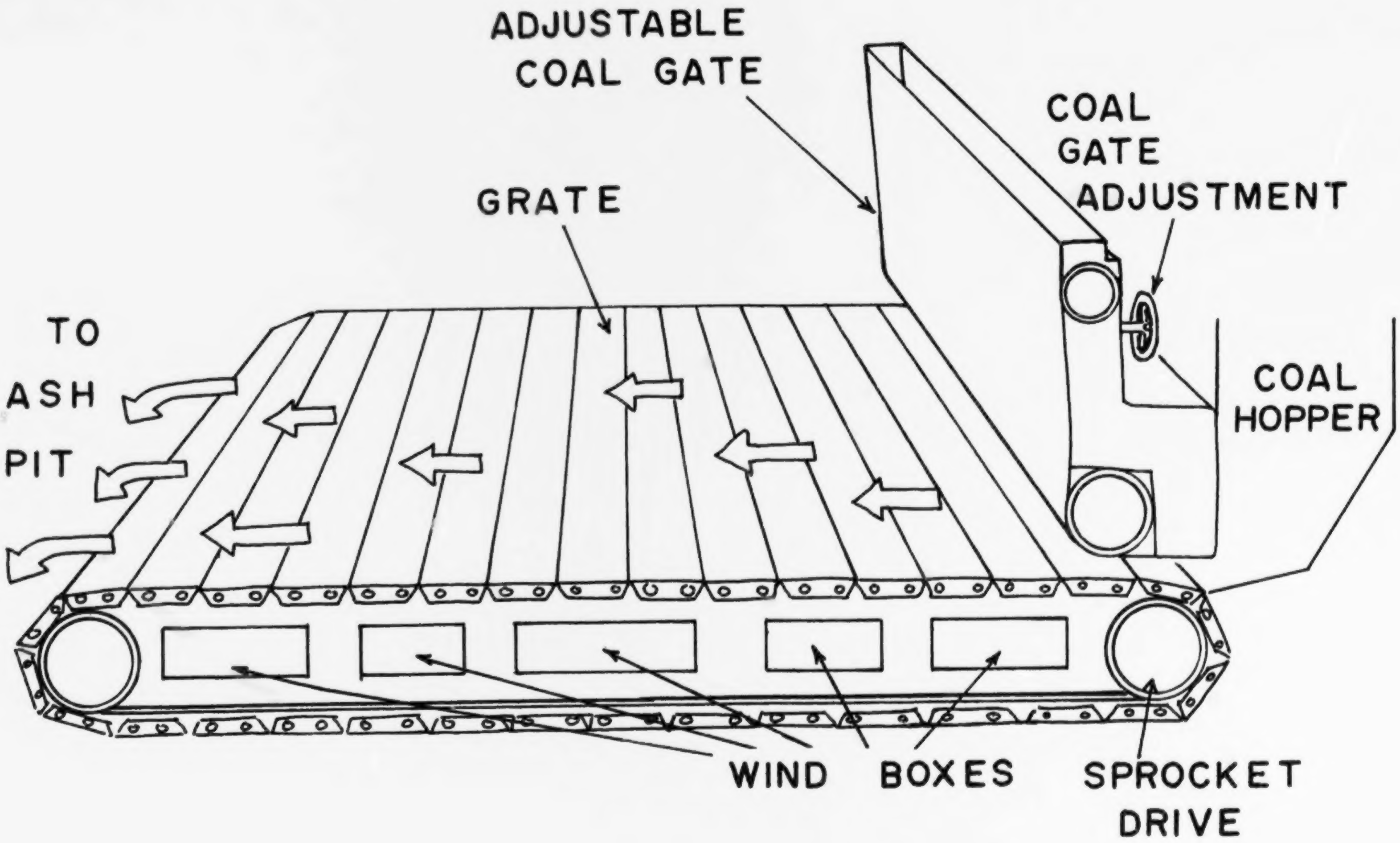
Reference: *Steam Plant Operation*
Combustion Engineering

Procedure: After studying the information and the listed references, complete the following assignment.

Assignment:

1. Describe a chain-grate stoker.
2. Describe how coal enters and ashes leave the furnace of a chain-grate stoker.

(Assignment continued on page 108)


ADJUSTABLE COAL GATE
COAL GATE ADJUSTMENT
GRATE
TO ASH PIT
COAL HOPPER
WIND BOXES
SPROCKET DRIVE

CHAIN GRATE STOKER

7-A-1-1

3. What is an ignition arch?
4. Is an ignition arch needed for a chain-grate furnace?
5. How is the coal-feed regulated for a chain-grate stoker?
6. What characteristics must the coal used on chain-grate stokers have?
7. How is air supplied to a chain-grate stoker?
8. How would you bank a fire on a chain-grate stoker?

Objective: Be able to describe side and overfeed stokers and how they work.

Information: After learning about chain- or traveling-grate stokers, you may conclude that the boiler operator's job seems to be getting a little bit easier. It's certainly a lot better than handfiring coal. So . . . let's look a little further into this stoker firing.

The side-feed stokers are used in medium-sized boilers and can use natural draft. The grates are inclined, and coal moves slowly down the grates to the middle of the furnace, where a clinker grinder is located.

The overfeed stoker differs from the side-feed stoker in that its grates slope from the front of the firebox to the back. The ash is removed from the bottom of the firebox by dumping grates. The front overfeed stoker is also equipped with an ignition arch, which ignites the coal as it enters the firebox.

References: *Steam Plant Operation*
Combustion Engineering
Elementary Steam Power Engineering
Boiler Room Questions and Answers

Procedure: After reading the information and studying the listed references, answer the following questions and be prepared to discuss each.

Assignment:

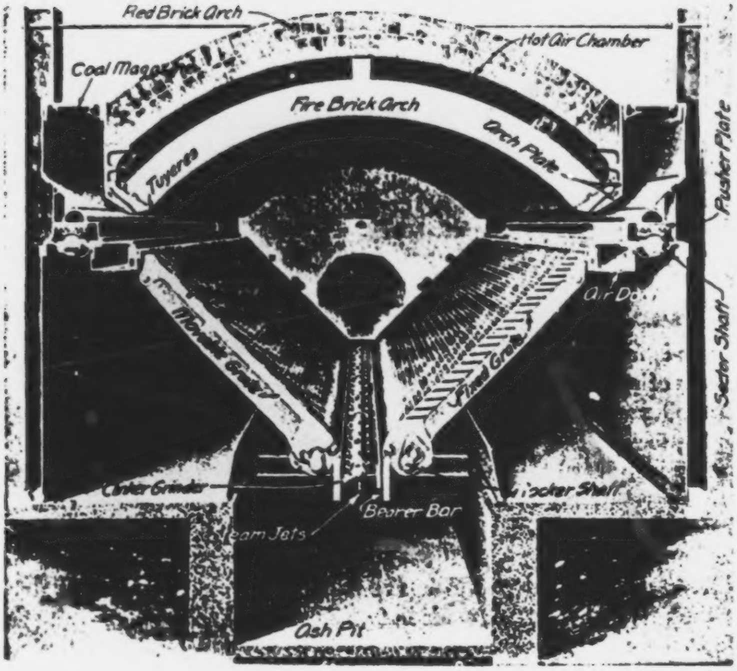
1. Describe a front overfeed stoker.

2. How does a side-feed stoker differ from a front-feed stoker?

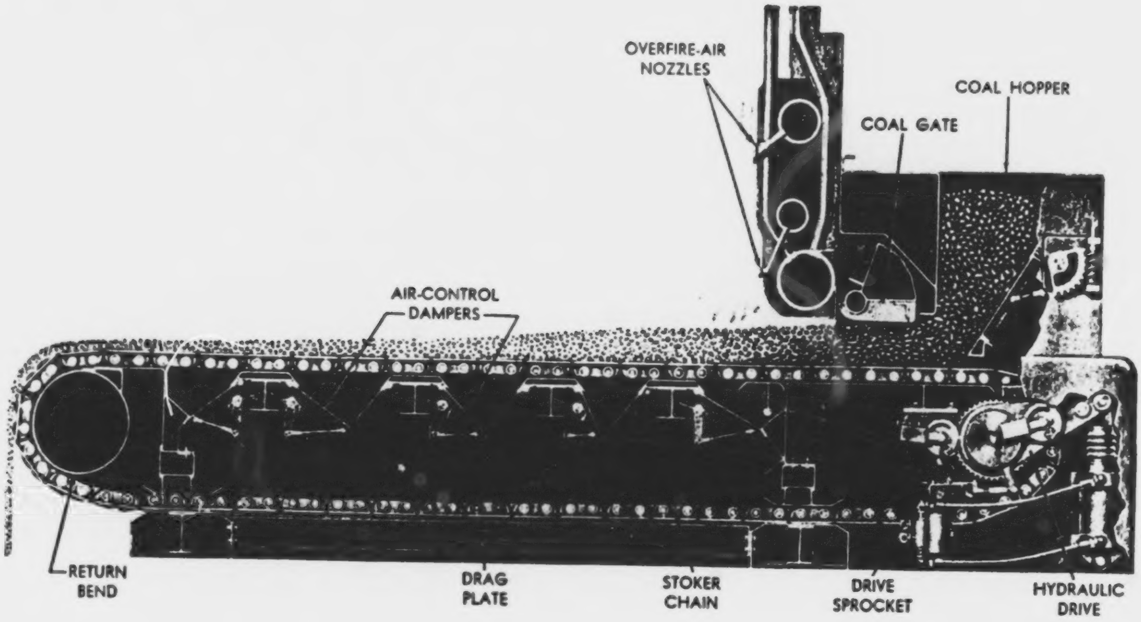
3. Describe how coal is introduced into the furnace of both the front- and side-feed stokers.

4. What purpose does the clinker grinder serve, and on what type of stoker is it found?

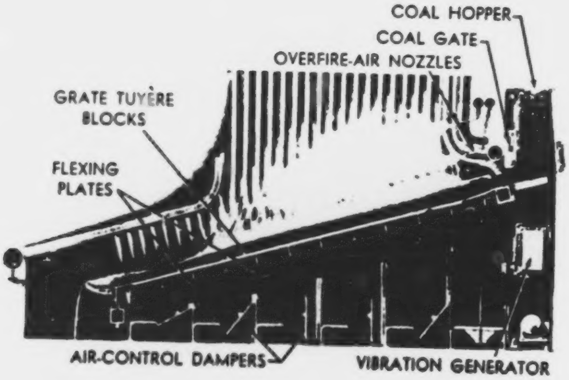
5. What purpose does an ignition arch serve?


Red Brick Arch
Hot Air Chamber
Coal Maga
Fire Brick Arch
Arch Plate
Tuyeres
Pusher Plate
Air Do
Sector Shaft
Movable Grate
Fixed Grate
Clinker Grinder
ocker Shaft
Bearer Bar
team Jets
Ash Pit

SIDE FEED STOKER


OVERFIRE-AIR NOZZLES
COAL HOPPER
COAL GATE
AIR-CONTROL DAMPERS
RETURN BEND
DRAG PLATE
STOKER CHAIN
DRIVE SPROCKET
HYDRAULIC DRIVE

OVERFEED CHAIN GRATE STOKER


COAL HOPPER
COAL GATE
OVERFIRE-AIR NOZZLES
GRATE TUYÈRE BLOCKS
FLEXING PLATES
AIR-CONTROL DAMPERS
VIBRATION GENERATOR

OVERFEED VIBRATING-GRATE STOKER

Objective: Be able to describe a spreader stoker and tell how it works.

Information: Spreader stokers are sometimes referred to as sprinkler stokers. They are designed for firing small-size coal. The coal is sprinkled or showered on the grates. The fine particles burn in suspension, while the larger ones fall to the grates. This is supposed to prevent the grates from being covered with "green" coal, thus keeping the firebed hot. Installations using this type of stoker usually have not over 10,000 square feet of boiler heating surface.

The main parts of the stoker are the coal hopper, a conveyor type of feeder, a distributor, and drive unit. The coal hopper supplies coal to the conveyor feeder and then to the distributor, which throws it out in a sprinkled form to be burned in suspension or on the grates. Air for combustion is supplied both from under the grates and over the fire to complete combustion. This type of stoker uses bituminous coal and operates with a very thin fuel bed.

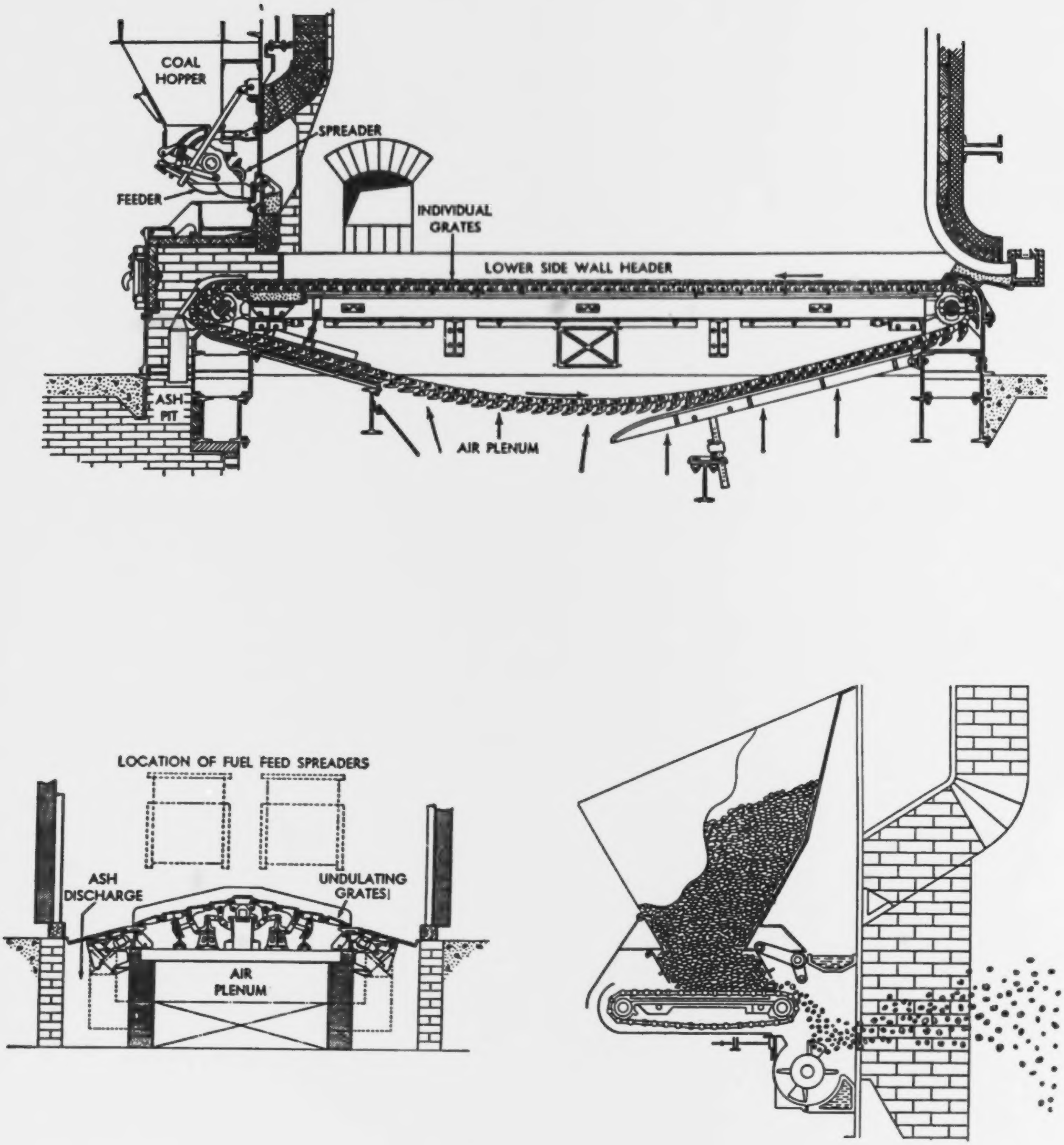
The rate of combustion is controlled by the speed of the drive on the feeder and the amount of air supplied under and over the fire.

Reference: *Steam Plant Operation*
Elementary Steam Power Engineering

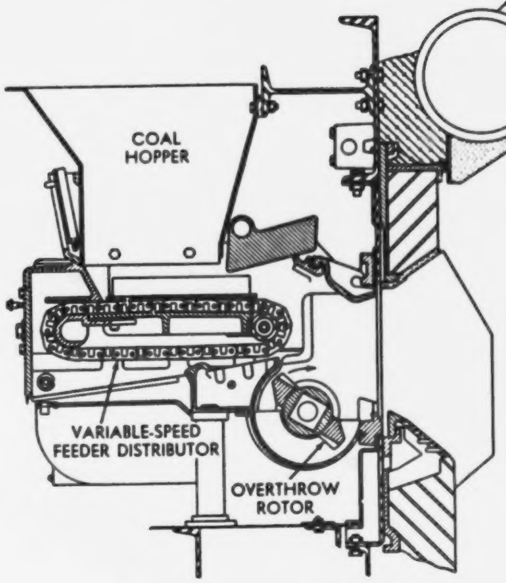
Procedure: After studying the information and the listed references, answer the following questions.

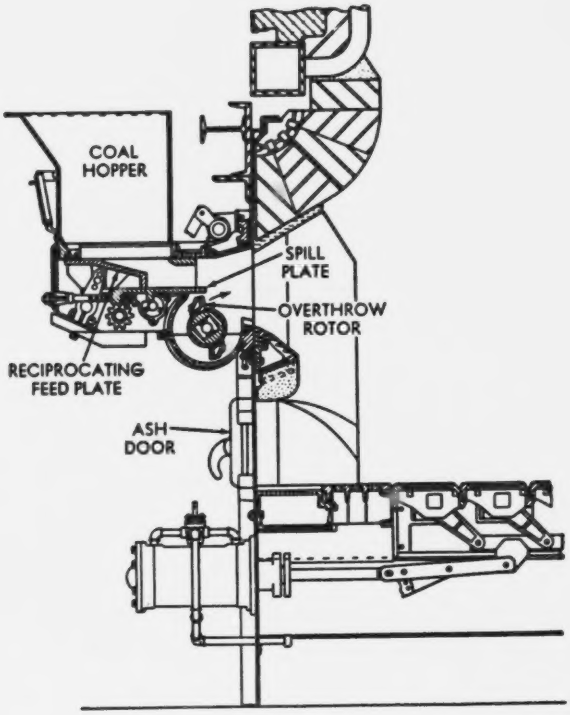
Assignment:

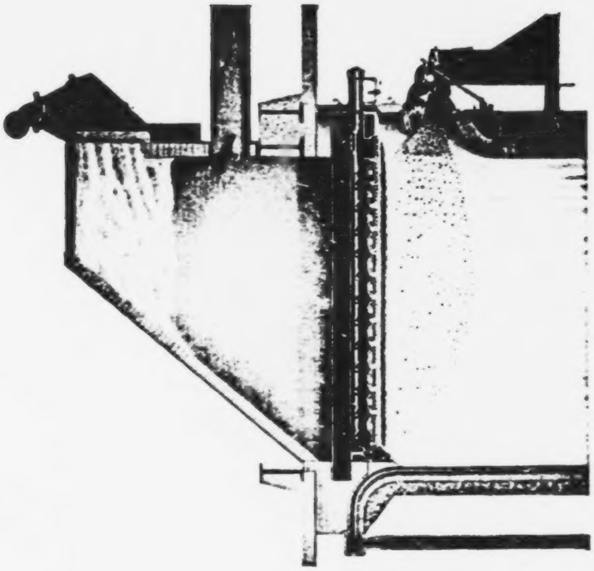
1. What are the main parts of a spreader stoker?
2. How does the spreader stoker supply coal to the furnace?
3. Why must the furnace volume be larger when using a spreader stoker?
4. What range of sizes may be burned using a spreader stoker?
5. Why are clinkering difficulties reduced when using a spreader stoker?
6. Why are these stokers not suitable for smaller heating boilers?
7. How is it possible to carry fluctuating loads successfully?
8. How would you bank a fire on a spreader stoker?


COAL HOPPER
SPREADER
FEEDER
INDIVIDUAL GRATES
LOWER SIDE WALL HEADER
ASH PIT
AIR PLENUM
LOCATION OF FUEL FEED SPREADERS
ASH DISCHARGE
UNDULATING GRATES
AIR PLENUM

SPREADER STOKER


COAL HOPPER
VARIABLE-SPEED FEEDER DISTRIBUTOR
OVERTHROW ROTOR


COAL HOPPER
SPILL PLATE
OVERTHROW ROTOR
RECIPROCATING FEED PLATE
ASH DOOR



SPREADER STOKERS

7-A-3-2

Objective: Be able to describe underfeed stokers and tell how they work.

Information: There are many different types of underfeed stokers, but the basic principle is the same – coal is introduced into a hopper and is delivered into the front of a retort, where pusher blocks distribute the coal back and up. The coal is delivered by either a piston-type ram or a screw. The lateral movement of the moving grate bars slowly moves the burned-out refuse toward the ash grates. If you looked into the firebox, you would see that the lateral movement of the grates creates the effect that the grates are breathing.

The underfeed stoker is capable of burning either anthracite or bituminous coal. If it burns a coal containing a high volatile content, some form of overfire air is needed to control smoke.

Reference: *Steam Plant Operation*
Elementary Steam Power Engineering
Boiler Room Questions and Answers
Combustion Engineering

Procedure: After reading the information and studying the listed references, answer the following questions and be prepared to discuss them in class.

Assignment:

1. a) What type of draft is used on underfeed stokers?
   b) Why is this type of draft used?
   c) What method is used to prevent smoke when burning high-volatile coal?

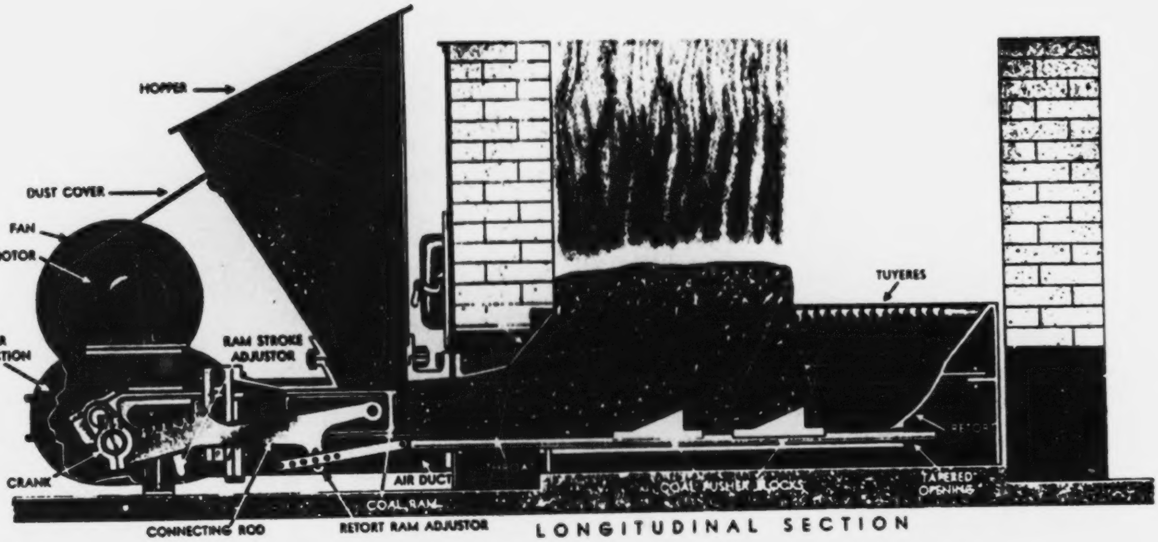
2. List the types of stoker drives used and describe how the rate of coal feed is controlled with each type.

3. What are the disadvantages of using dumping grates?

4. What do some stokers use in place of dumping grates?

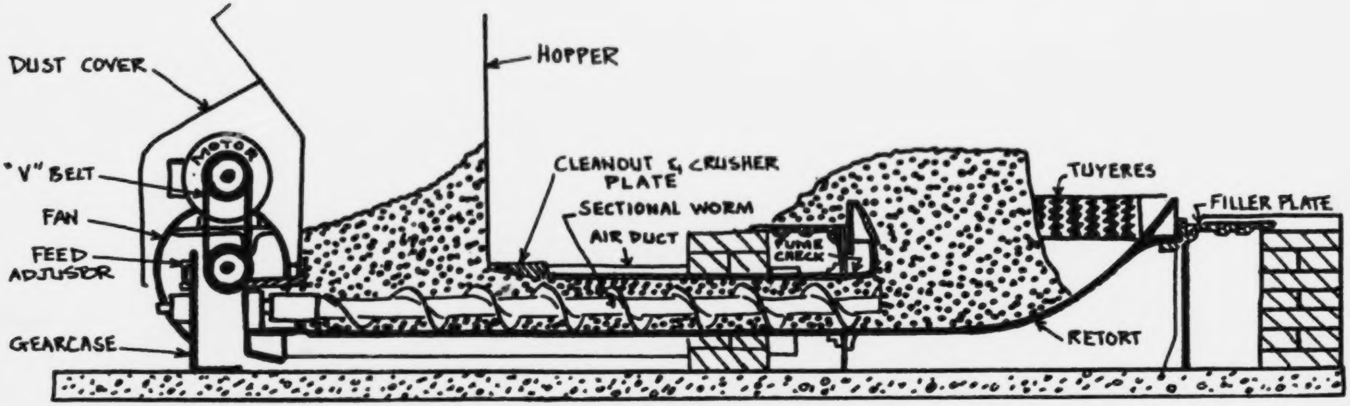
5. On multiple-retort stokers, how are irregularities in the fuel-bed corrected?

(Assignment continued on page 118)


HOPPER
DUST COVER
FAN
MOTOR
GEAR REDUCTION
RAM STROKE ADJUSTOR
TUYERES
RETORT
CRANK
AIR DUCT
COAL RAM
COAL PUSHER BLOCKS
TAPERED OPENING
CONNECTING ROD
RETORT RAM ADJUSTOR
LONGITUDINAL SECTION

RAM-TYPE UNDERFEED STOKER

7-A-4-1


DUST COVER
"V" BELT
FAN
FEED ADJUSTOR
GEARCASE
MOTOR
HOPPER
CLEANOUT & CRUSHER PLATE
SECTIONAL WORM
AIR DUCT
FUME CHECK
TUYERES
FILLER PLATE
RETORT

SCREW-TYPE UNDERFEED STOKER

6. a) Why is it that no special arches are needed on underfeed stokers?
   b) How does this help improve the efficiency?

7. Before a stoker is put into operation, what precautions should be taken?

8. a) How would you lay a fire bed in this type of stoker? (Use a Skelly stoker as an example.)
   b) How would you light off and build up pressure?

9. How would you bank this type of stoker?

10. How would you run the fire out and take the boiler off the line?

11. How can you insure satisfactory and long maintenance-free operation of an underfeed stoker?

Objective: Be able to calculate the amount of coal being consumed per hour.

Information: On a chain-grate stoker it is possible to determine the rate at which the coal is being used if you know the following –

1. Width of stoker in feet
2. Depth of coal-bed in feet
3. Speed of stoker in feet per minute

Then you can find the number of cubic feet used per minute as follows:

$$\text{Cu. ft. burned per min.} = \text{Width} \times \text{Depth} \times \text{Speed}$$

(1) $$\text{Cu. ft./min.} = W \times D \times S$$

The next step is to convert the cu.ft./min. to pounds/hour by using the conversions

48 lb./cu. ft. for bituminous, and
60 lb./cu. ft. for anthracite.

Therefore bituminous-coal pounds per hour will be

(2) $$\text{Pounds per hour} = \text{cu. ft./min.} \times 60 \times 48$$

And then to tons per hour,

(3) $$\text{Tons per hour} = \frac{\text{Pounds /Hour}}{2000}$$

Example 1: A chain-grate stoker 6 feet wide is burning bituminous coal. The grate speed is 4 inches per minute, and the coal is 4 inches deep. At what rate is coal used, in tons per hour?

$$\text{cu. ft./min.} = W \times D \times S$$

$$\text{cu. ft./min.} = 6 \times \frac{4}{12} \times \frac{4}{12}$$

$$\text{cu. ft./min.} = \frac{2}{3}$$

$$\text{Pounds per hour} = \text{cu. ft./min.} \times 60 \times 48$$

$$\text{lb./hr.} = \frac{2}{3} \times 60 \times 48$$

$$\text{lb./hr.} = 1920$$

$$\text{Tons/hr.} = \frac{\text{lb./hr.}}{2000}$$

$$\text{Tons/hr.} = \frac{1920}{2000}$$

$$\text{Tons/hr.} = .96$$

Example 2: A chain-grate stoker 10 feet wide is burning anthracite coal. The grate speed is 6 inches per minute, and the coal is 6 inches deep. At what rate is coal being used, in tons per hour?

$$\text{Cu. ft./min.} = W \times D \times S$$

$$\text{Cu. ft./min.} = 10 \times \frac{6}{12} \times \frac{6}{12}$$

$$\text{Cu. ft./min.} = 2.5$$

$$\text{Pounds per hour} = \text{cu. ft./min.} \times 60 \times 60$$

$$\text{lb./hr.} = 2.5 \times 60 \times 60$$
$$\text{lb./hr.} = 9{,}000$$

$$\text{Tons/hr.} = \frac{\text{lb./hr.}}{2000}$$

$$\text{Tons/hr.} = \frac{9{,}000}{2{,}000}$$

$$\text{Tons/hr.} = 4.5$$

Reference: *Steam Plant Operation*

Procedure: After studying the above information and the listed references, complete the following problems.

Assignment:

Complete the following problems, using the values indicated.

1. Chain grate 20′ wide
   grate speed 5″ per min. —— bituminous coal
   coal depth 3″

2. chain grate 18′ wide
   grate speed 3″ per min. ——— anthracite coal
   coal depth 5″

3. chain grate 15′ wide
   grate speed 4″ per min. ——— anthracite coal
   coal depth 4″

4. chain grate 10′ wide
   grate speed 5″ per min. ——— coke breeze*
   coal depth 6″

5. chain grate 22′ wide
   grate speed 4″ per min. ——— anthracite coal
   coal depth 5″

6. chain grate 20′ wide
   grate speed 5″ per min. ——— anthracite coal
   coal depth 4″

* Note: Coke breeze weighs 40 pounds per cubic foot.

Objective: Be able to explain how a coal-pulverizing system functions.

Information: A basic coal-pulverizing system consists of the following components, as shown on sketch 7–B–1–1: There is an overhead coal bunker where the coal is stored and a belt conveyor at the base of the bunker that feeds coal to the coal scale. The conveyor is controlled by the position of the scale. When the scale is in an up position, the conveyor will run until the scale is filled with the proper amount of coal. If the scale moves down, ready to dump, the conveyor stops. From the coal scale the coal moves to the feeder, which controls the amount of coal that is fed into the pulverizer. The feeder is usually of the rotating-blade type, and its speed controls the amount of coal delivered to the pulverizer.

Once the coal is in the pulverizer, the process begins of grinding it to the consistency of talcum powder. This is accomplished by means of steel balls or rollers rotating around a bowl. The coal is crushed as it passes between the surfaces. Hot air is introduced into the pulverizer mill to dry the coal and prevent caking. The air mixes with the powdered coal and passes through the exhauster on its way to the burner throat. The air that is introduced into the mill is known as primary air; after passing through the windbox it is known as secondary air.

The coal is burned suspended in air; it requires a relatively high furnace temperature to maintain good combustion – approximatey 3000°F. Pulverized coal is highly explosive, and care must be taken when burning it. You must maintain a flame in the furnace at all times and also a negative pressure. If the pressure in the furnace becomes positive, there is a possibility of the flame's traveling back to the mill, causing an explosion in the mill.

Reference: *Steam Plant Operation*
Elementary Steam Power Engineering

Procedure: After studying the information and the references given, answer the following questions.

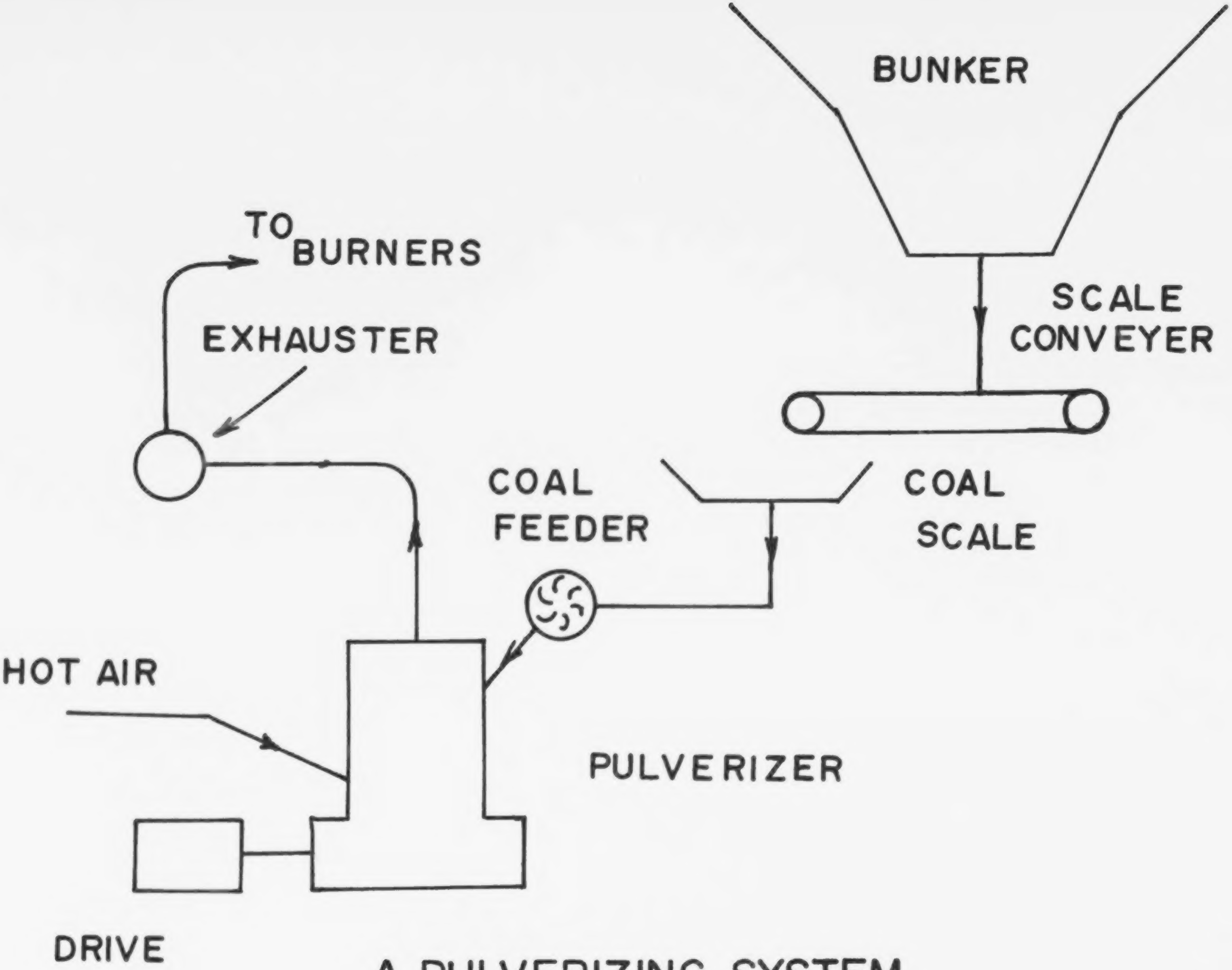
Assignment:

1. Name the principal parts of a coal-pulverizer system.

2. Describe the purpose of each part.

(Assignment continued on page 124)

7-B-1-1


BUNKER
TO BURNERS
SCALE CONVEYER
EXHAUSTER
COAL FEEDER
COAL SCALE
HOT AIR
PULVERIZER
DRIVE

A PULVERIZING SYSTEM

3. Why are both primary and secondary air needed in this system?
4. Describe how the system functions.
5. What are some of the dangers of this system?
6. What are some of the advantages of using this system?
7. What types of plants can efficiently use pulverizers?

Objective: Be able to explain the purpose, types, and location of air heaters.

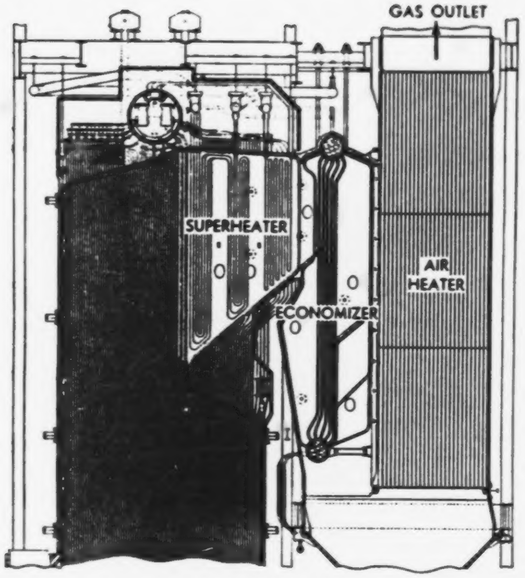
Information: In recent years the increase in fuel costs has caused demands for higher plant efficiency. One large loss in steam boilers is the heat in the flue gases going up the stack. To reduce this stack temperature, economizers and air preheaters are used. The air heater is located between the boiler and the stack (See figure 165, page 237, "Elementary Steam Power Engineering" and figure 7–C–1 –1.) There are two basic types of air heaters, the convection type and the regenerative type. The convection type is either a plate or tubular preheater. Sketches of typical heaters are shown on the next few pages.

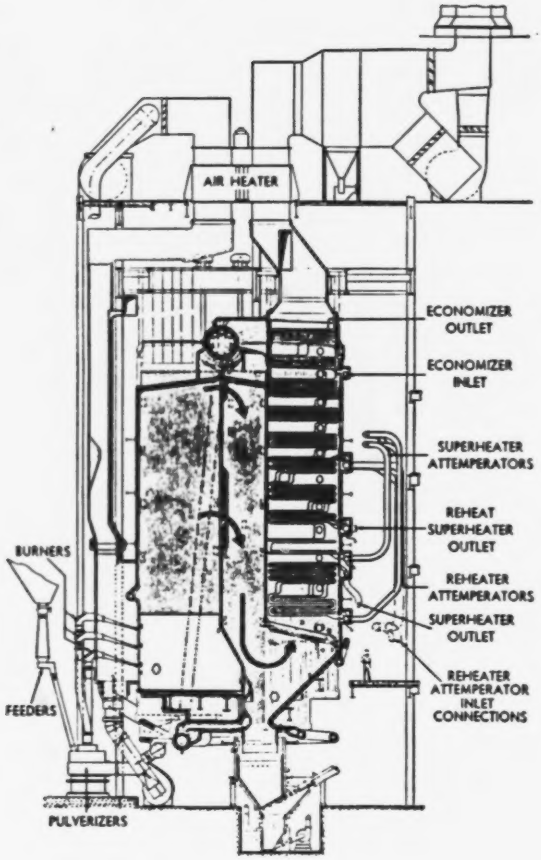
Reference: *Elementary Steam Power Engineering*
Steam Plant Operation

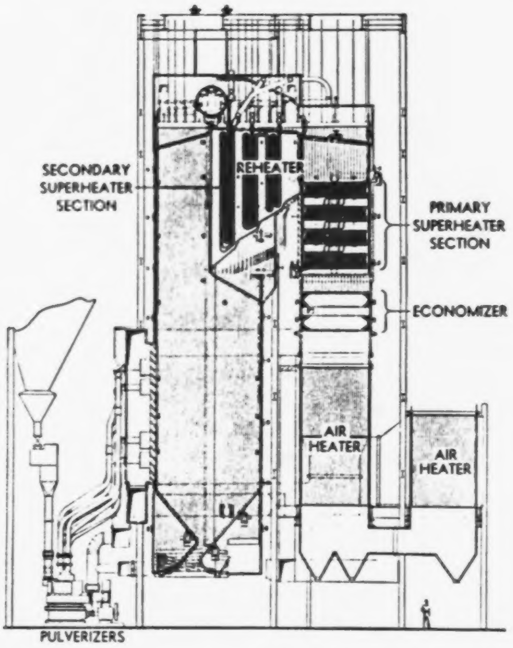
Procedure: After reading the information and studying the listed references, answer the following questions and be prepared to discuss each in class.

Assignment:

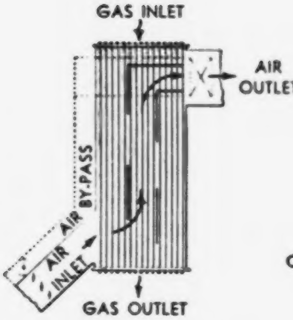
1. What purpose does an air preheater serve?
2. How are air heaters classified?
3. Where are air heaters located?
4. What maintenance problems, if any, do air preheaters present?
5. Why is it necessary to use induced-draft fans in conjunction with air heaters?


GAS OUTLET
SUPERHEATER
AIR HEATER
ECONOMIZER

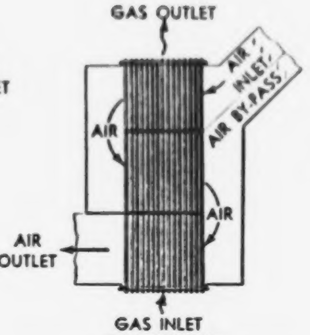

AIR HEATER
ECONOMIZER OUTLET
ECONOMIZER INLET
SUPERHEATER ATTEMPERATORS
REHEAT SUPERHEATER OUTLET
REHEATER ATTEMPERATORS
SUPERHEATER OUTLET
REHEATER ATTEMPERATOR INLET CONNECTIONS
BURNERS
FEEDERS
PULVERIZERS


SECONDARY SUPERHEATER SECTION
REHEATER
PRIMARY SUPERHEATER SECTION
ECONOMIZER
AIR HEATER
AIR HEATER
PULVERIZERS

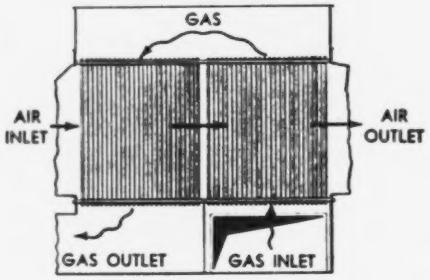
LOCATION OF AIR HEATERS


GAS INLET
AIR OUTLET
AIR BY-PASS
AIR INLET
GAS OUTLET

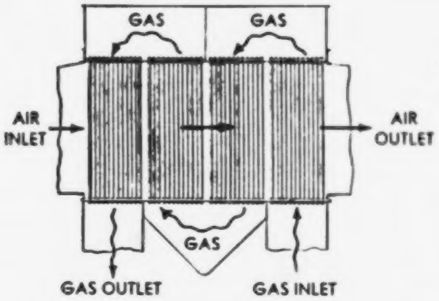
GAS DOWNFLOW
AIR AND GAS COUNTERFLOW,
SINGLE PASS


GAS OUTLET
AIR INLET
AIR BY-PASS
AIR
AIR
AIR OUTLET
GAS INLET

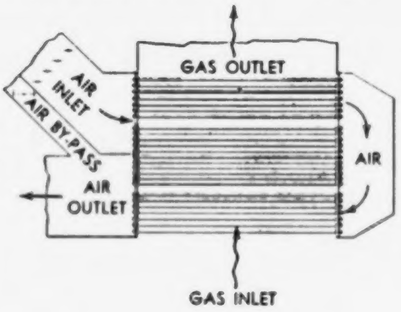
GAS UPFLOW
AIR COUNTERFLOW, THREE PASS


GAS
AIR INLET
AIR OUTLET
GAS OUTLET
GAS INLET

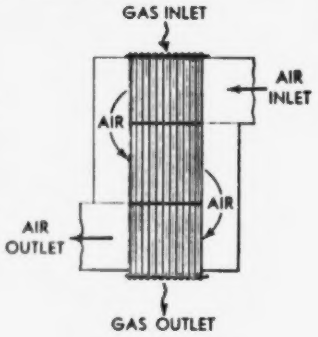
GAS UPFLOW AND DOWNFLOW
AIR COUNTERFLOW, SINGLE PASS


GAS
GAS
AIR INLET
AIR OUTLET
GAS
GAS OUTLET
GAS INLET

GAS UPFLOW AND DOWNFLOW
AIR COUNTERFLOW, SINGLE PASS

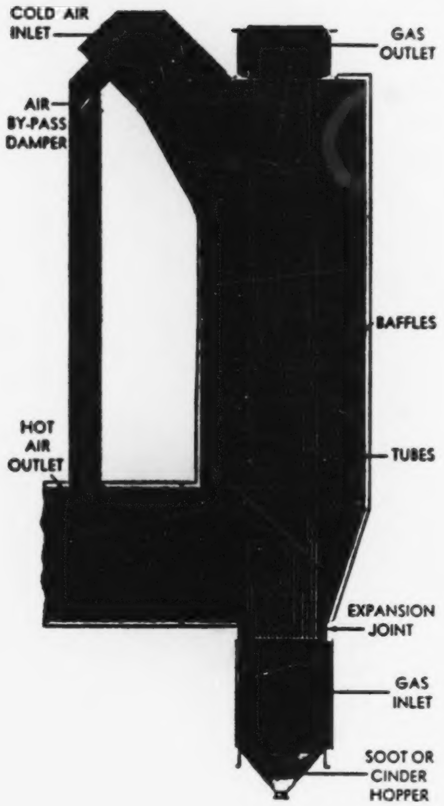

GAS OUTLET
AIR INLET
AIR BY-PASS
AIR
AIR OUTLET
GAS INLET

GAS UPFLOW
AIR COUNTERFLOW, TWO PASS


GAS INLET
AIR INLET
AIR
AIR
AIR OUTLET
GAS OUTLET

GAS DOWNFLOW
AIR PARALLEL FLOW, THREE PASS

ARRANGEMENTS OF TUBULAR AIR HEATERS


COLD AIR INLET
AIR BY-PASS DAMPER
HOT AIR OUTLET
GAS OUTLET
BAFFLES
TUBES
EXPANSION JOINT
GAS INLET
SOOT OR CINDER HOPPER

TUBULAR AIR PREHEATER

7-C-1-3

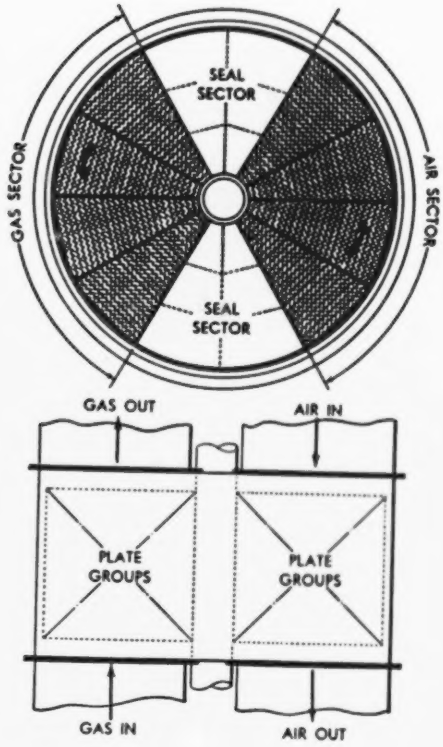
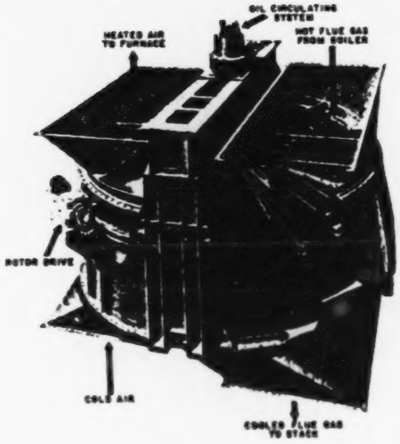
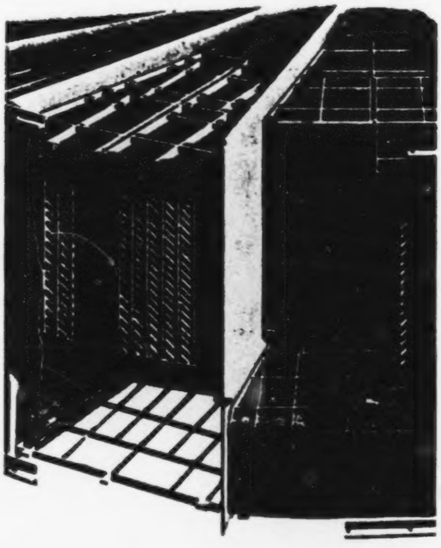

SEAL SECTOR
GAS SECTOR
AIR SECTOR
SEAL SECTOR
GAS OUT
AIR IN
PLATE GROUPS
PLATE GROUPS
GAS IN
AIR OUT

PLATE-TYPE AIR PREHEATER


OIL CIRCULATING SYSTEM
HEATED AIR TO FURNACE
HOT FLUE GAS FROM BOILER
ROTOR DRIVE
COLD AIR
COOLED FLUE GAS TO STACK

LJUNGSTROM AIR PREHEATER



HEATING SURFACE OF
LJUNGSTROM AIR PREHEATER

Objectives: Be able to describe how air heaters are constructed.

Be able to tell when air heaters can be used to increase plant efficiency.

Information: You already know that there are two basic types of heaters, the convection type, which are either tubular or plate, and the regenerative type. They all serve the same purpose, that is, to retrieve some of the heat going up the stack. They must be constructed of a good grade of steel and must be well insulated to allow the temperature of the air to be controlled.

Plants using pulverizers need heated air in the mill to dry out the coal. This air must be watched so that it does not get too hot, or it will cause problems in the mill. Usually there is a source of outside air that can be blended automatically to maintain an air temperature of about 200° – 210°F. in the mill. Air heaters can be used successfully in plants having a fairly constant load.

It is important to watch the temperature of the air entering the stack. If it gets too low it will cause sweating in the outlet side of the air heater – and you know what soot and water create!

Air heaters are located in the direct path of the gases of combustion. They are continually being bombarded with soot and fly ash. It is most important that they be kept clean. This is usually accomplished by soot blowers. They must also be examined at annual inspection for any signs of corrosion. If tubes or plates are eaten away, your gases will mix, and the incoming air will wind up going up the stack with the flue gases.

References: *Elementary Steam Power Engineering*
Steam Plant Operation

Procedure:s After reading the information and listed references, answer the following questions and be prepared to discuss each in class.

Assignment:

1. Describe in detail the construction of a plate-type convection air heater and explain how it works.

2. Describe in detail the construction of a tubular-type convection air heater and explain how it works.

3. Describe a regenerative heater, its construction and how it works.

4. What is the reason for using bypass dampers on air preheaters?

5. Why can pulverizers use a higher combustion air temperature than stoker-fired units?

Objective: Be able to tell how positioning and metering combustion-controls function.

Information: There are three elements that must be controlled in any combustion-control system. They are:

1. Fuel supply
2. Air supply
3. Ratio of fuel to air supply

There are three basic types of automatic controls that will do this. They are:

1. On-off operation
2. Positioning
3. Metering

In Science Manual 2 we covered the on-off type of combustion control, which we said was used on small high- and low-pressure boilers. This unit will cover positioning and metering controls that are used on medium- and large-sized boilers.

The **positioning control** operates from the steam header pressure, which actuates a master control unit, which then relays pressure signals to slave units that in turn control the fuel and air supplied to the furnace. The whole system must be adjusted so that any change in the steam pressure will produce a proportional change in the fuel and air supply. The positioning method of control assumes that one setting of a given control always produces the same results. This of course is not necessarily true, due to wear on the linkage and pins of the controls. Although it is possible to maintain a fairly constant steam pressure, combustion efficiency at times can drop off.

Metering control is a further development of the positioning control. This does not rely on the assumption that the fuel and air flow are directly proportional to the steam pressure. The metering system measures the flow of steam (difference of pressure across an orifice) and balances it against signals for more or less fuel and air. This system is more likely to keep combustion efficiency at a high level.

The outlet or uptake damper on both of these systems is controlled by the furnace pressure during automatic operation, or manually from the control panel when on hand control.

The advantages of using combustion controls are:

1. Better fuel/air ratios, resulting in improved efficiency and less smoke and soot
2. Better water circulation, increasing life of boiler tubes
3. Better feed-water regulation due to more even firing rates (less fluctuation of water level)
4. A more even superheat temperature
5. Elimination of very high combustion rates

Reference: *Steam Plant Operation*
Elementary Steam Power Engineering

Procedure: After studying the above information and the references, answer the following questions.

Assignment:

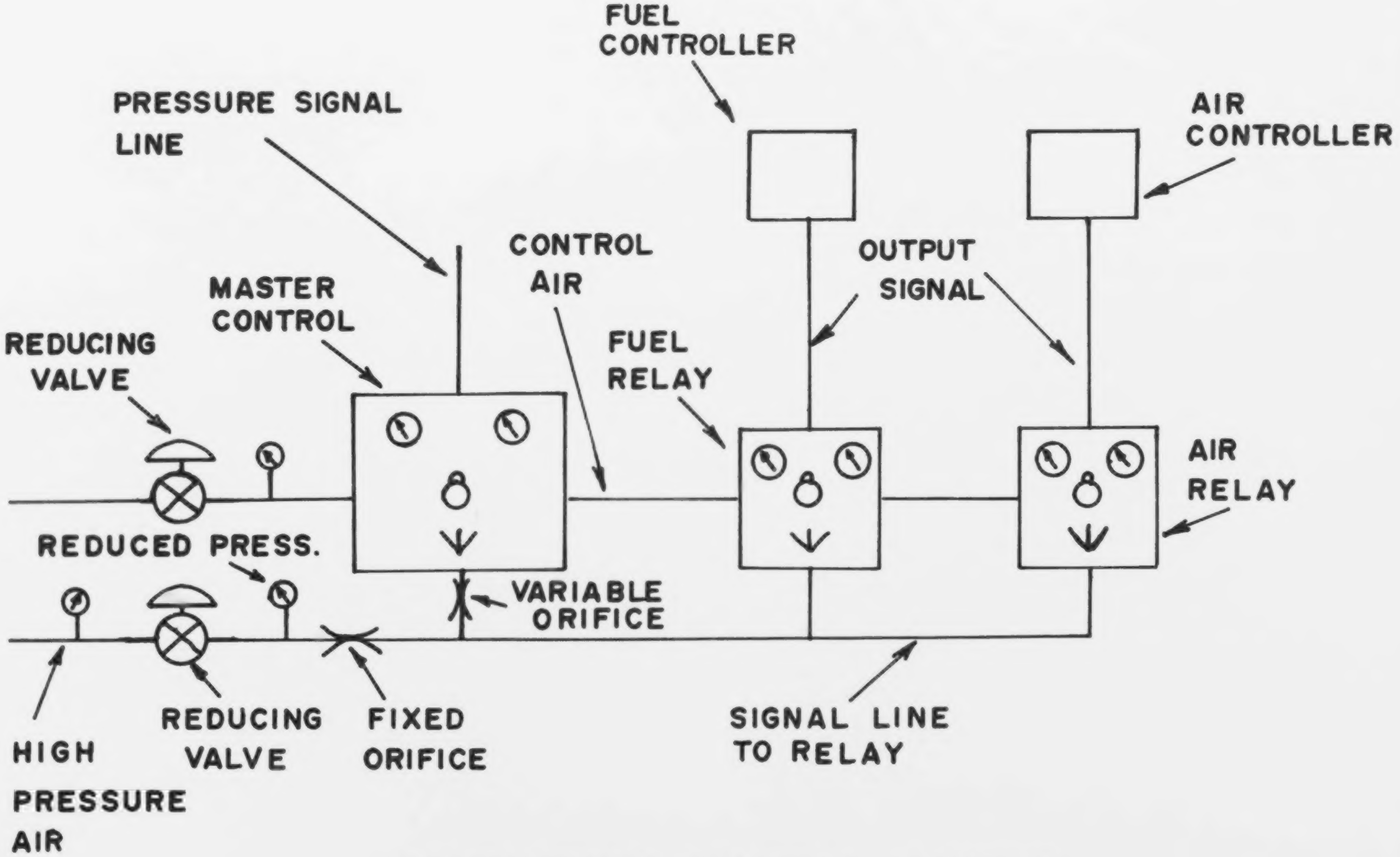
1. What three elements must be controlled in an automatic combustion control system?

2. Describe a positioning-type automatic combustion-control system.

3. How does a metering system differ from a positioning system?

4. What are the advantages of having a combustion-control system?

5. How is the outlet damper controlled on an automatic boiler?


FUEL CONTROLLER
PRESSURE SIGNAL LINE
AIR CONTROLLER
CONTROL AIR
OUTPUT SIGNAL
MASTER CONTROL
REDUCING VALVE
FUEL RELAY
AIR RELAY
REDUCED PRESS.
VARIABLE ORIFICE
HIGH PRESSURE AIR
REDUCING VALVE
FIXED ORIFICE
SIGNAL LINE TO RELAY

COMBUSTION-CONTROL SYSTEM
METERING TYPE

7-D-1-1

135

Objectives: Be able to describe the various methods used for the combustion of oil.

Be able to state the advantages and disadvantages of each method.

Information: The combustion of oil in a furnace depends upon a burner's being able to deliver the correct quantity of oil, properly atomized, and at the correct temperature for burning. The **pressure–atomizing burner** does it in the following manner. Oil with a pressure of at least 100 p.s.i. is heated to the proper temperature– depending upon grade –and admitted to a burner barrel. At the end of the barrel is a sprayer plate and orifice that causes the oil to swirl, gaining velocity as it leaves the orifice. At the same time air enters around the barrel, past a diffuser ring that rotates the air in the opposite direction to that of the oil. The oil and air mix and the mix is now ready to be ignited.

The **steam-atomizing burner** uses steam instead of high pressure, and a sprayer plate to atomize the oil. The steam atomizing burner is either an outside- or inside-mixing type. They both atomize the oil by having the steam cut across the stream of oil, thereby breaking it up into small droplets. Air is supplied through a diffuser ring to mix with the oil for combustion.

The **rotary-cup burner** uses oil with a low pressure and atomizes it in the following way. The oil enters the burner tube, which ends in a spinning cup. The oil drops onto the cup and spins with the cup, increasing in velocity as it reaches the edge. The oil leaves the cup spinning and in a hollow-cone shape. At the same time that this is happening, primary air is being forced past an angular air-vane that rotates the air in the opposite direction to that of the oil. The oil and air meet, and atomization of the oil is completed. Secondary air is introduced to complete combustion.

All of the above methods are used to burn oil.

Pressure-atomizing is used in medium to large plants and does require a more expensive installation. Steam-atomizing burners can burn just about any kind of fuel oil and are relatively inexpensive. Their one drawback is that they require 2% to 5% of the generated steam to operate. They are used as standby burners on many pulverized-coal burners. Rotary-cup burners are built in a complete assembly and are used on small- to medium-sized units; they are well-suited for firetube package boilers.

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Procedure: After studying the above information and the listed references, answer the following questions.

Assignment:

1. Name three methods of burning oil in a furnace.
2. Describe each method in detail.
3. State the advantages and disadvantages of each type of burner.
4. What is the most common use for each type?

Methods of Hand-Firing Coal — Assignment 8–B–1

Objective: Be able to describe the methods of hand-firing coal.

Information: There are two basic types of coal used in power boilers. Hard coal, called anthracite, has a high fixed-carbon content, and soft coal, called bituminous, has a high volatile content.

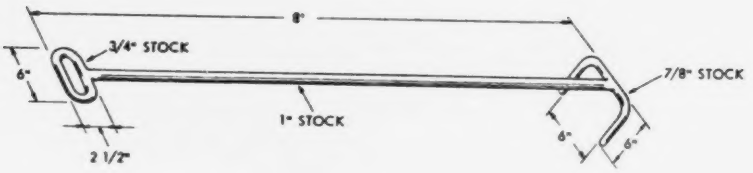
Because of the differences in their natures, hard and soft coals cannot be fired in the same manner. Soft coal has to be worked with a rake and slice bar, where hard coal does not. Fig. 8–B–1–1 shows the types of firing tools needed when hand-firing a boiler. The dimensions given in the sketches are those suggested by the Bureau of Mines.

References:
Steam Plant Operation
Boiler Room Questions and Answers
Low Pressure Boilers

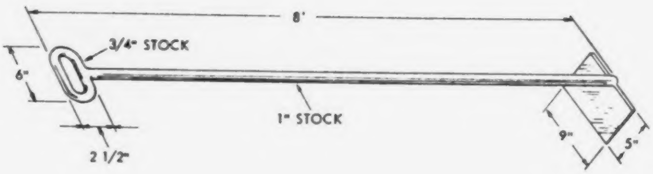
Procedure: After reading the information and studying the listed references, answer the following questions and be prepared to discuss each in class.

Assignment:

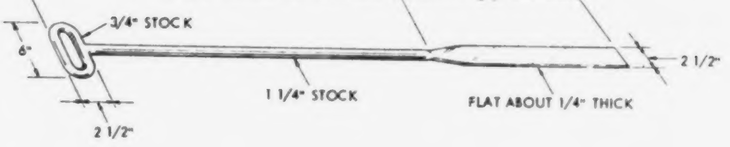
1. Describe how you would lay a fire bed in a hand-fired boiler.
2. Discuss the two methods of coaling over a fire.
3. How does the furnace volume differ between soft-coal and hard-coal boilers?
4. Why will soft coal smoke while hard coal will not?
5. What will happen if too much green coal is added when using the spreading method of hand-firing?
6. Describe two methods of cleaning fires on stationary grates.
7. Which fuel requires the larger grate opening, anthracite or bituminous? Explain.
8. Are grates in a hand-fired boiler set level or inclined? Explain.


8'
3/4" STOCK
6"
7/8" STOCK
1" STOCK
6"
6"
2 1/2"

RAKE


8'
3/4" STOCK
6"
1" STOCK
9"
5"
2 1/2"

HOE


6'6"
2'6"
3/4" STOCK
6"
2 1/2"
1 1/4" STOCK
FLAT ABOUT 1/4" THICK
2 1/2"

SLICE BAR

Mechanical Firing of Coal — Stoker

Assignment 8–B–2

Objective: Be able to describe how to fire coal mechanically, using a stoker.

Information: You know from your previous lessons that there are many different types of stokers. Each stoker will require a slightly different operating procedure. There are certain steps to follow that will be the same for all stokers.

1. Inspect hopper to make sure it is free of foreign material.
2. Grease all fittings; check oil in gear box.
3. Check to make sure stoker is free of all tools, rags, etc.
4. Run coal in to cover grates.
5. Lay waste rags and wood on top of coal.
6. Crack open outlet damper.
7. Ignite wood, and as coal starts to catch, slowly add a little air from forced draft fan.
8. Engage stoker and start it feeding slowly.
9. As soon as ignition arch is hot, and as coal starts to burn more freely, open up more on outlet damper.
10. Allow boiler to warm up slowly to prevent uneven expansion of metal or brickwork.

References: *Steam Plant Operation*
Low Pressure Boilers
Elementary Steam Power Engineering

Procedure: After reading the information and listed references, answer the following questions and be prepared to discuss each.

Assignment:

1. Describe in detail the procedure you would follow in laying a fire-bed in a chain-grate stoker, how you would light it up, warm it up, and cut boiler in on line.

2. How would you regulate the coal being fed to a chain-grate stoker?

3. How would you bank an underfeed stoker? What steps would you take to protect the pusher blocks in the retort?

Objectives: Be able to list the conditions necessary for the successful burning of pulverized coal.

Be able to describe how pulverized coal is fired.

Information: To burn pulverized coal successfully, the following conditions are necessary:

1. Coal ground to the proper consistency for burning in suspension.
2. A furnace temperature high enough to maintain continuous combustion.
3. Sufficient air to complete combustion.
4. A furnace volume large enough to complete combustion before the gases of combustion enter the first pass.
5. Turbulence throughout the furnace (that is, a constant motion in all directions).

If the coal is not properly pulverized in the mill, it will not burn completely in the furnace but will tend to stick on the tube surfaces in the first pass. This can cause a buildup that can cut down the flow of combustion gases.

A pulverized-coal burner is normally started by having an oil- or gas-fired burner run for at least 2 days to bring the furnace temperature up to approximately 2400°F. The coal is then fed to the burner, igniting from the oil or gas. Over a 24-hour period the furnace temperature increases to about 3000°F. It is now able to maintain continuous combustion, and the oil or gas burners are secured.

At the mill, heated air is introduced as primary air to dry the coal. Additional air enters through air registers at the burners. This completes combustion of the coal with a minimum amount of excess air.

The furnace has to have a large volume because of the amount of volatile gases given off by the coal. Turbulence is necessary to insure proper mixing of air and fuel. Turbulence is usually obtained by the arrangement of the burner and the secondary-air register in the furnace.

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Procedure: After studying the above information and the listed references, complete the following questions.

Assignment:

1. State the conditions necessary to burn pulverized coal.
2. Explain why each of the conditions in question 1 is important.
3. Describe how coal is taken from the coal bunker and is prepared for burning in the furnace.

Objectives: Be able to explain what is meant by the term "heat balance."

Be able to determine the heat balance of a steam boiler.

State the formula for the efficiency of a boiler.

Information: Fuel fed into a boiler is converted (by burning) into heat, and the heat is absorbed by the water in the boiler. Not all of the heat that could be got from that fuel is actually used to heat the water, however. Some is wasted, in various ways.

The **heat balance** of a boiler consists of the sum of all the heat used up in the boiler – most of it usefully, but some of it wasted. It is called a balance because the sum of all the heat units consumed, either usefully or wastefully, must equal (balance) the number of heat units supplied by the fuel.

The heat balance of a boiler would be:

Heat available in the fuel = heat absorbed by the water in the boiler + losses of heat

Let: A = heat available in the fuel
B = heat absorbed by the water in the boiler
C = losses of heat

Then: $A = B + C$

And: Efficiency of unit = B/A

The losses that occur in a boiler include:

1. Heat carried away in the dry chimney gases (about 11%)
2. Incomplete combustion of the fuel (about 1.5%)
3. Evaporation of moisture in the fuel (less than 1%)
4. Evaporation of moisture formed by burning the hydrogen (about 3%)
5. Heating of moisture in the air used for combustion (less than 1%)
6. Unburned combustibles in the ash (about 3%)
7. Radiation and other small losses (about 4%)

Preventable losses are losses that you do have some control over when operating a boiler. They are:

1. Heat carried away in the dry chimney gases
2. Incomplete combustion of the fuel
3. Unburned combustibles in the ash

From a study of the values given you will note that the losses total approximately 24.5% — this would give the steam boiler an efficiency of 75.5%

The general formula for the efficiency of a boiler is:

$$\text{Efficiency} = \frac{\text{No. of Btu's in steam}}{\text{No. of Btu's available in the fuel}}$$

Reference: *Steam Plant Operation*
Elementary Steam Power Engineering

Procedure: After studying the information and listed references, answer the following questions.

Assignment:

1. What is a heat balance?

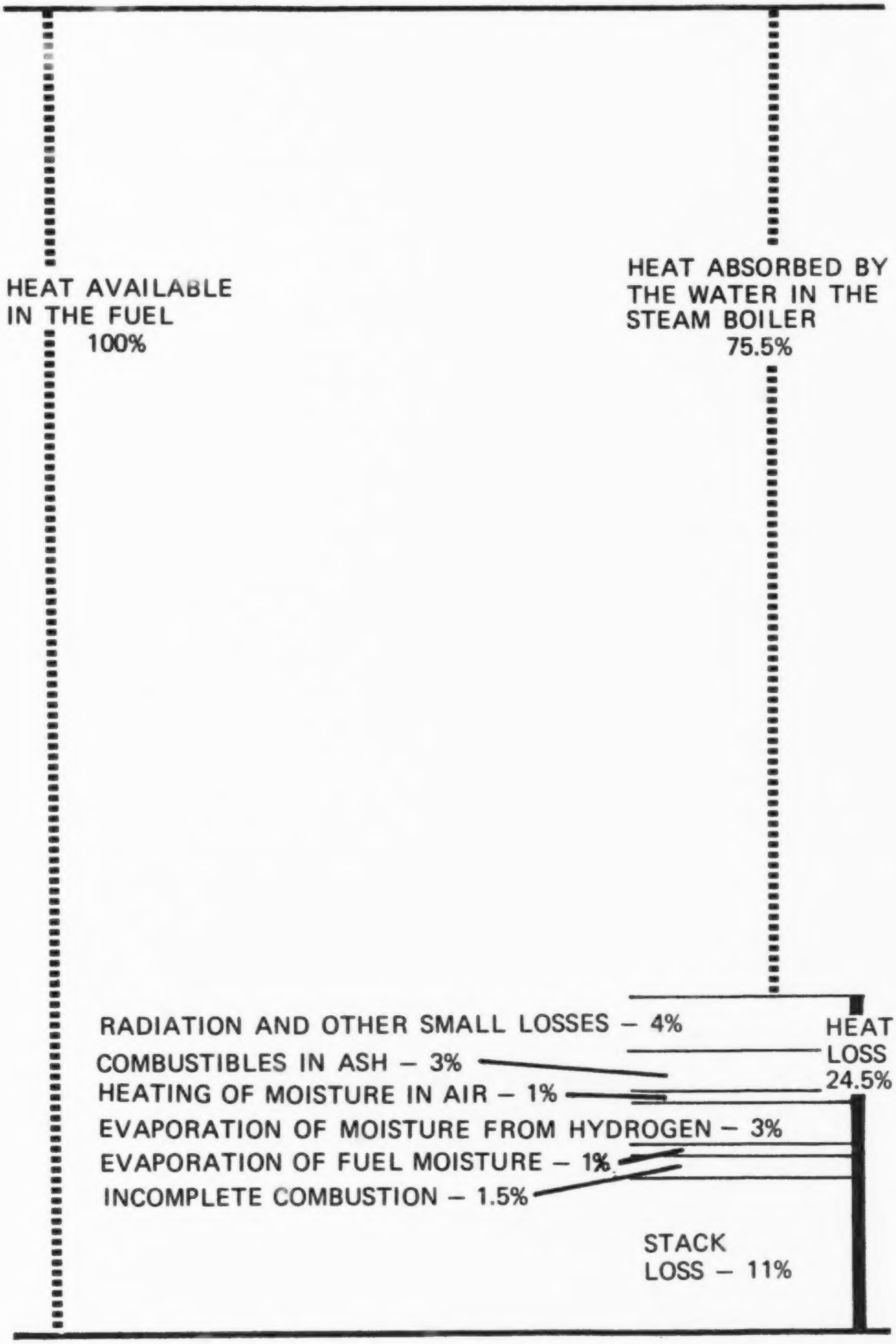
2. List all possible heat losses in a steam boiler.

3. When operating a steam boiler, what losses do you have control over?

4. In a sketch, show the distribution of heat in a boiler from 1 gallon of oil with a heat content of 150,000 Btu per gallon. Show the heat in Btu's.

5. What is the efficiency of the boiler in question 4?

HEAT BALANCE OF BOILER



Objectives: Be able to state the factors that can reduce the heat balance of a boiler.

Information: From your last lesson you know that there are seven basic losses in a steam boiler's heat balance. We also know that three of the losses are somewhat controllable. They are:

1. Heat carried away in the dry chimney gases.
2. Incomplete combustion of the fuel.
3. Unburned combustibles in the ash.

Let us first look at all the conditions in a boiler that could possibly affect the heat carried away in the dry chimney gases.

1. Soot on the heating surfaces of the boiler would reduce the heat transfer rate from gases to water.
2. Scale or deposits on the heat-transfer surfaces on the water side of the boiler would also affect heat transfer.
3. Broken baffles in the gas passes of a boiler have the effect of short-circuiting the gases past heating surfaces, once again reducing the heat-transfer.
4. Too much air will carry heat past the transfer surfaces faster, and therefore less heat will be transmitted.

In each case above, less heat is abosrbed by the boiler and therefore the efficiency of the unit decreases.

Soot, scale, and broken baffles will be indicated by higher than normal stack temperatures and a lower evaporation rate. With broken baffles, hot spots can develop in the gas passages. Excess air will be indicated when you do a flue-gas analysis.

Incomplete combustion and unburned fuel can be avoided with the careful attention of a good operator. It is the engineer's duty in a well-run steam-plant to test and check frequently for all factors that will affect a good heat balance and hence reduce the efficiency of the unit.

Reference: *Steam Plant Operation*
Elementary Steam Power Engineering

Procedure: After studying the information and listed references, answer the following questions.

Assignment:

1. What are the three controllable losses in a boiler's heat balance?

2. What is the effect of the following on a steam boiler in regard to the heat balance?
   a. Soot
   b. Scale
   c. Broken baffles
   d. Excess air

3. How can incomplete combustion be avoided?

4. How would you go about determining if there was soot or scale in an operating boiler?

5. How would you know if you have a broken baffle in a boiler?

Objective: Be able to describe how draft systems function on coal-, oil-, and gas-fired furnaces.

Information: The main purpose of an effective draft system on a boiler is to supply sufficient air to complete the combustion process and to carry away through the stack all of the waste products of combustion.

As you may recall, there are three basic types of draft used on boilers – natural,forced, and induced. **Natural draft** is created by using a high stack. Since the gases rise when heated they tend to go up the stack. Forced and induced drafts are mechanical means of creating drafts. In **forced draft**, the blower or fan forces air into the furnace; in **induced draft**, the blower removes the products of combustion from the furnace.

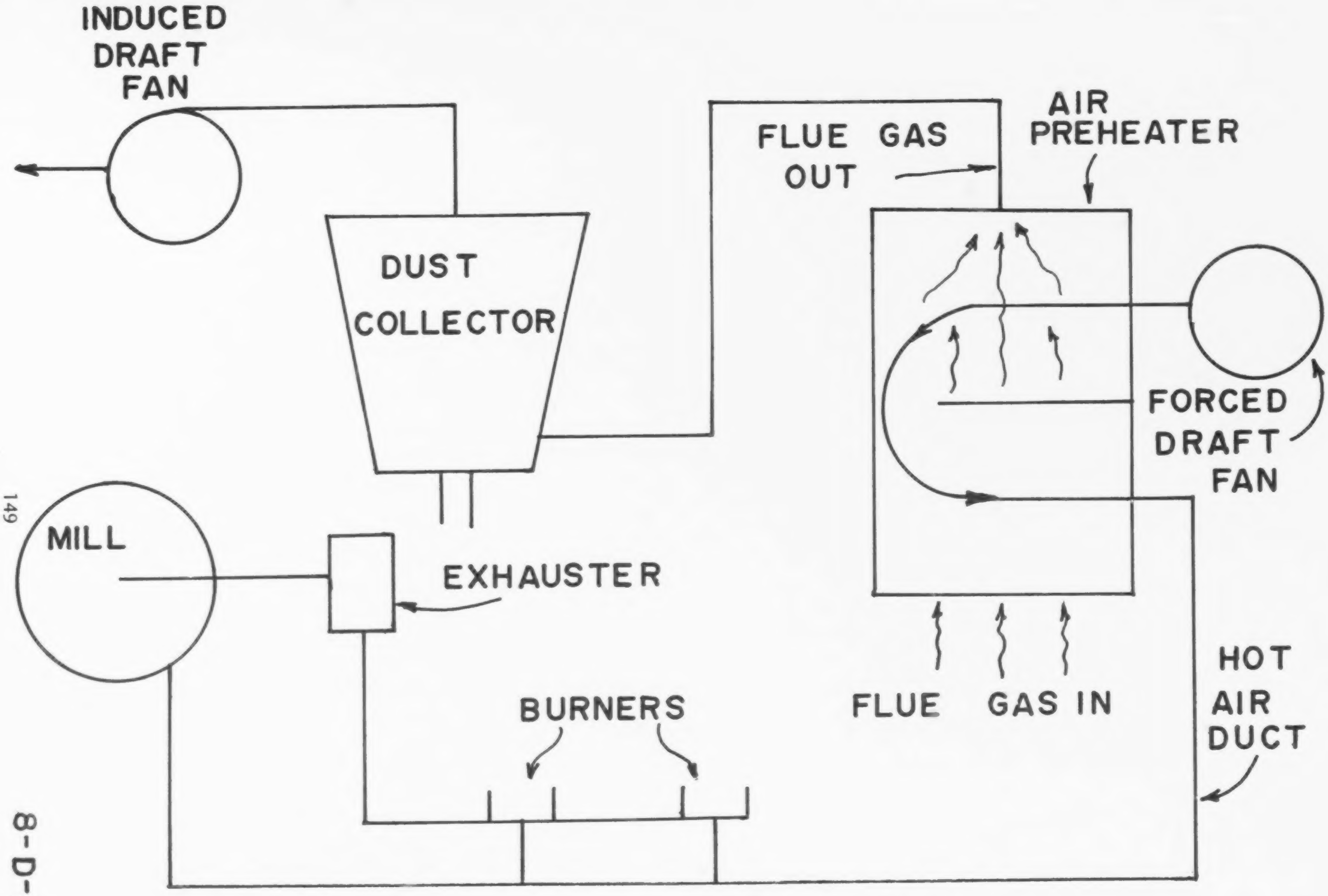
The draft system on an oil-burning unit would be as follows:

1. Natural draft using a relatively high stack. The burner would most likely be an air- or steam-atomizing unit.
2. Forced draft but still using the high stack. The burner would be a rotary-cup, pressure-, or steam-atomizing unit.
3. Forced and induced draft, with either a low or high stack (depending upon the draft losses through accessories such as air preheaters and economizers). The burner would be a pressure-atomizing unit.

Gas-burning units can replace the oil-burning units above with the same draft systems or with very slight changes.

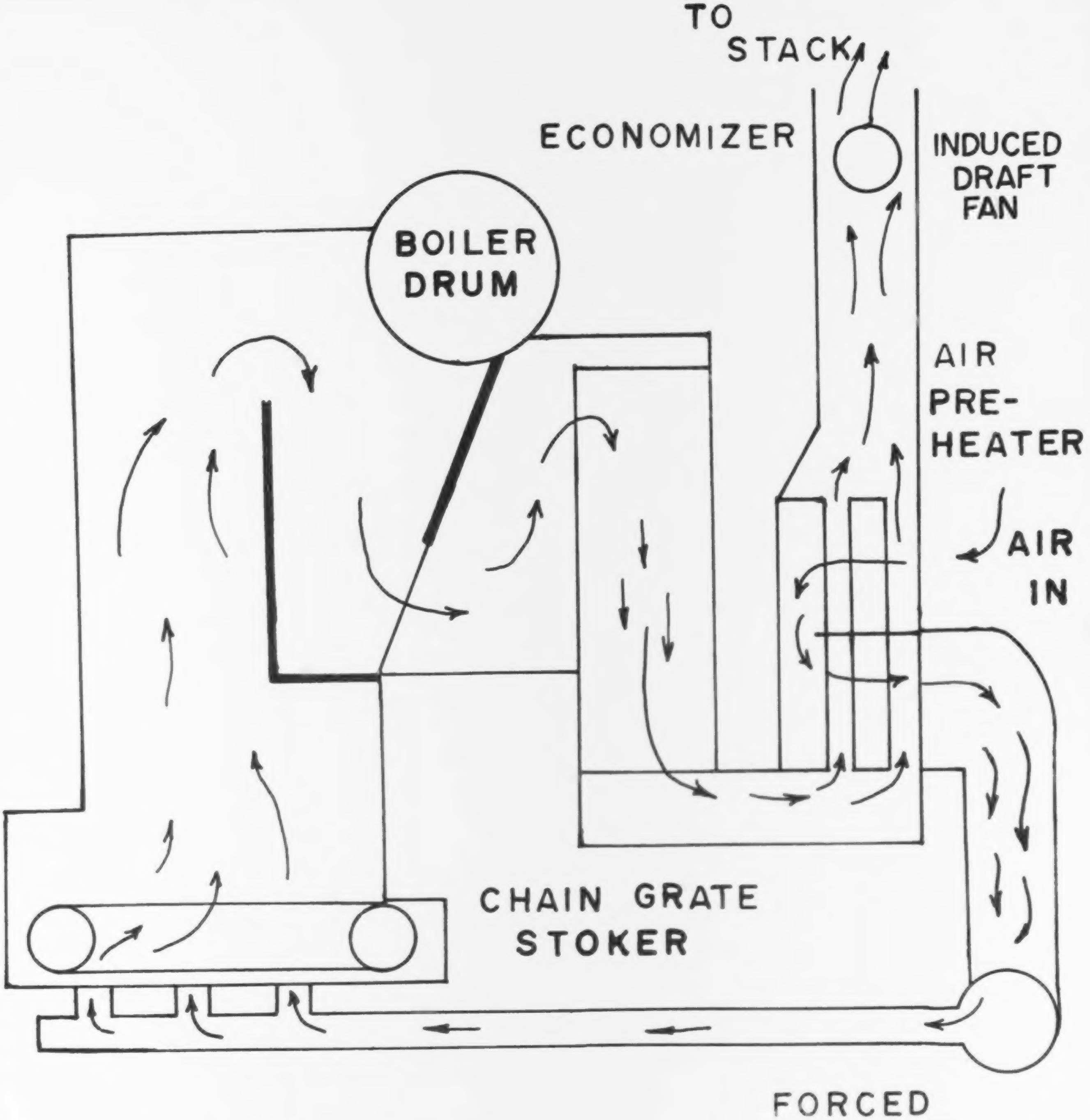
Stokers that burn anthracite coal need under-fire air but very little over-fire air, because of the small amount of volatile matter present in anthracite coal. When burning bituminous, it is necessary to have under- and over-fire air because of the larger amount of volatile gases being distilled from the coal. Both forced and induced draft are used with stokers, and high combustion rates can be attained.

Pulverized-coal systems use a combination of forced and induced draft. The air in these systems is heated as it passes through an air preheater that is placed at the end of the last pass of the boiler, where the heat in the flue gas can warm it. The heated air increases combustion efficiency and is also used in the mill to dry the coal.


INDUCED DRAFT FAN
DUST COLLECTOR
FLUE GAS OUT
AIR PREHEATER
FORCED DRAFT FAN
MILL
EXHAUSTER
BURNERS
FLUE GAS IN
HOT AIR DUCT

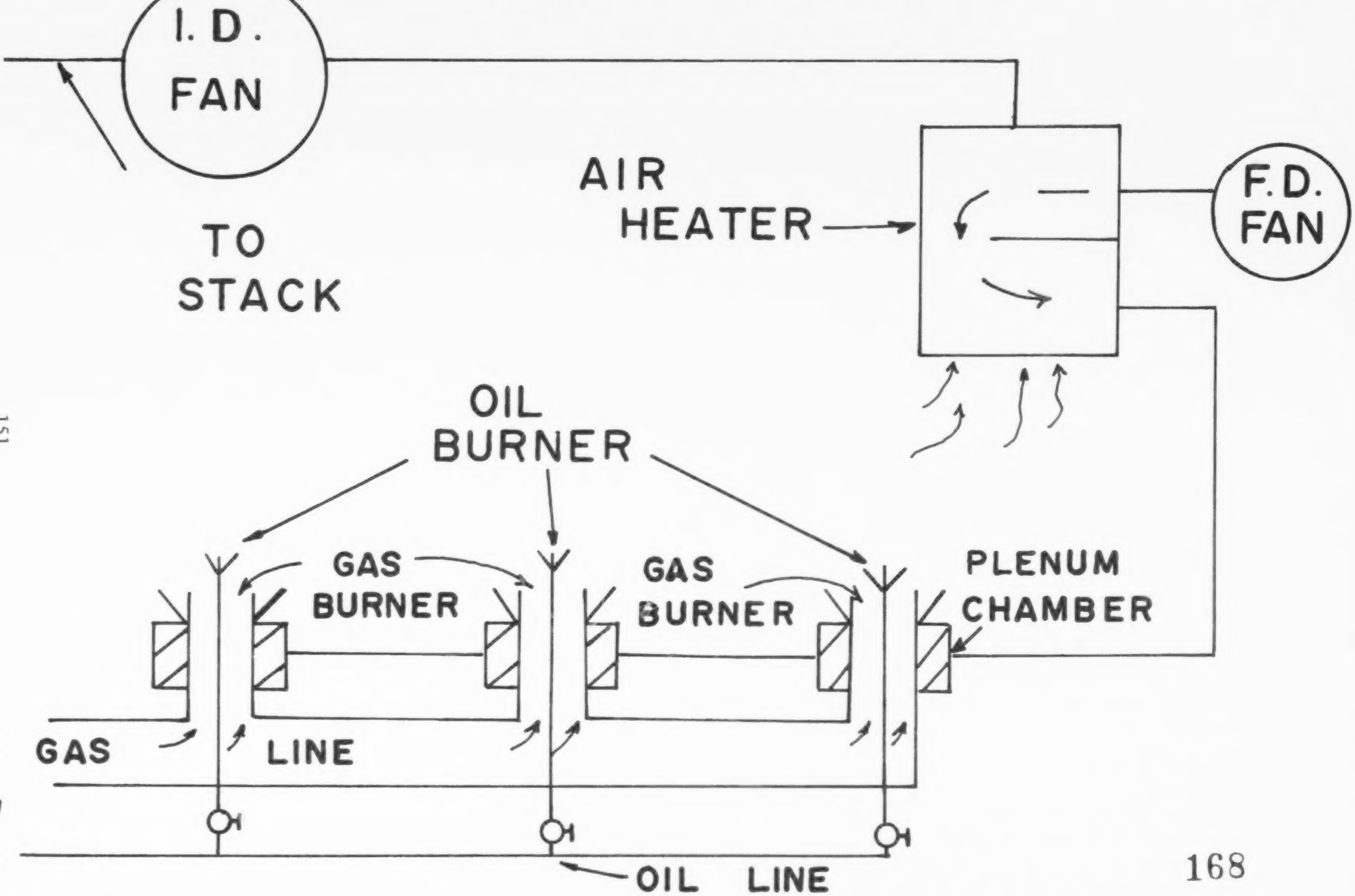
AIR PREHEATER IN A PULVERIZED-COAL PLANT

8-D-I-I


TO STACK
ECONOMIZER
INDUCED DRAFT FAN
BOILER DRUM
AIR PRE-HEATER
AIR IN
CHAIN GRATE STOKER
FORCED DRAFT FAN

AIR PREHEATER IN A CHAIN-GRATE STOKER

OIL AND GAS DRAFT SYSTEM


I. D. FAN
TO STACK
AIR HEATER
F. D. FAN
OIL BURNER
GAS BURNER
GAS BURNER
PLENUM CHAMBER
GAS LINE
OIL LINE

All of the above draft systems have been used effectively with coal-, oil-, and gas-burning units. The air entering the furnace of a boiler will be either primary or secondary and is controlled by the fuel/air ratio controller.

Most boilers today have a balanced draft system. This means that the gases leave the boiler at a rate to maintain a pressure in the furnace slightly below that of the atmosphere.

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Procedure: After studying the information and the listed references, answer the following questions.

Assignment:

1. Describe how an oil-burner draft system functions.
2. Describe how a stoker-fired-boiler draft system functions.
3. Describe how a pulverized-coal-burner draft system functions.
4. How is the draft in a furnace controlled?
5. Describe a balanced draft system.

Objective: Be able to determine the fan horsepower of a forced-draft fan.

Information: To find the forced-draft fan horsepower, the following formula may be used:

$$\text{Air HP} = \frac{\text{Quantity} \times \text{Pressure}}{6356}$$

$$= \frac{QP}{6356}$$

Where: Air HP = Horsepower (delivered)
Q = Quantity of air in cubic feet per minute
P = Inches of water pressure

In order to find the power needed for the drive on the fan, we must consider not only the horsepower of the air, but the efficiency of the fan. We will assume a value of 55% efficiency for the unit.

Example 1: A steam boiler uses 100 pounds of fuel per minute, and each pound of fuel requires 200 cubic feet of air. If the forced-draft fan has a discharge pressure of 3 inches of water, find the horsepower needed to drive the unit.

$$\text{Air HP} = \frac{QP}{6356} = \frac{100 \times 200 \times 3}{6356} = 9.44$$

$$\text{HP of drive} = \frac{\text{Air HP}}{\text{Eff.}} = \frac{9.44}{.55} = 17.2$$

Example 2: Find the HP required for the forced-draft fan on a boiler that generates 36,000 pounds of steam per hour and has an evaporation rate of 12 pounds of steam per pound of fuel. Assume fan discharge at 3″ water pressure and 200 cubic feet of air per pound of fuel.

In this problem we must first find Q:

$$Q = \frac{36{,}000 \text{ lb. steam}}{\text{hour}} \times \frac{1}{60 \text{ min}} \times \frac{200 \text{ cu.ft. air}}{\text{lb. of fuel}} \times \frac{1}{\frac{12 \text{ lb. steam}}{\text{lb. of fuel}}}$$

$$= \frac{36{,}000\ \cancel{\text{lb.}}\ \cancel{\text{steam}}}{1 \text{ hour}} \times \frac{1}{60 \text{ min}} \times \frac{200 \text{ cu. ft. air}}{\cancel{\text{lb.}} \text{ of } \cancel{\text{fuel}}} \times \frac{\cancel{\text{lb.}} \text{ of } \cancel{\text{fuel}}}{12\ \cancel{\text{lb.}} \text{ of } \cancel{\text{steam}}}$$

$$Q = \frac{36{,}000 \times 200}{60 \times 12} \text{ cu. ft. of air/min.}$$

Then:

$$\text{Air HP} = \frac{QP}{6356} = \frac{\frac{36{,}000 \times 200}{60 \times 12} \times 3}{6356} = \frac{36{,}000 \times 200 \times 3}{60 \times 12 \times 6356} = 4.72$$

$$\text{Drive HP} = \frac{\text{Air HP}}{\text{Eff.}} = \frac{4.72}{.55} = 8.58$$

Reference. *Steam Power Plant Engineering*

Procedure: After studying the information and the reference, complete the following assignment.

Assignment:

1. What is the formula for finding the horsepower requirements of a forced-draft fan? Explain the meaning of each term.

2. A boiler uses 150 pounds of fuel per minute, and each pound requires 190 cubic feet of air to burn to completion. If the forced-draft fan has a 3" water-pressure discharge, what horsepower is required to run the fan?

3. A boiler generates 100,000 pounds of steam per hour with an evaporation rate of 12.5 pounds of steam per pound of fuel. 200 cubic feet of air is needed per pound of fuel, and the forced-draft fan has a discharge pressure of 4" of water. Find the HP needed to drive the forced-draft fan.

4. A 4000 HP boiler with a pressure of 200 p.s.i. operates at full load. Determine the HP requirements for the forced-draft fan. Assume any values necessary.

Objectives: Be able to state the causes of certain problems with boiler water.

Be able to state the recommended limits for eight properties of boiler water.

Information: All raw water contains some gases and scale-forming salts. These scale-forming salts, when heated, settle out on the boiler's heating surfaces in the form of hard or soft scale. When we add chemicals to the boiler water, we change the scale-forming salts into a non-adhering sludge. This non-adhering sludge will settle to the bottom of the boiler and can be removed by using the bottom blow-down valves.

The gases are removed by heating the water before it enters the boiler and by using an oxygen scavenger.

We must treat the boiler water to prevent scale formation on tubes and heating surfaces, corrosion of the shell and tubes, caustic embrittlement at seams, and carryover of boiler water into superheater and steam lines. Lets take these one at a time.

1. **Scale:** Caused when calcium carbonate or magnesium carbonate are deposited on hot metal surfaces, forming a hard, brittle substance.

   Treatment: Add caustic soda and phosphate. This changes calcium carbonate and magnesium carbonate into calcium phosphate and magensium phosphate, which are non-adhering sludges.

   Tests: Hardness test – standard soap solution Phosphate test

   Boiler-water limits: 0 ppm of hardness
   phosphate – 20 to 40 ppm

2. **Corrosion:** Caused by oxygen and carbon dioxide.

   Treatment: Best removed by heating water before it enters the boiler. Sodium sulphite is also added to the boiler; this is an oxygen scavenger. The oxygen changes the sulphite to a sulphate.

   Test: For residual sulphite

   Boiler-water limits: 20–30 ppm

3. **Cautic embrittlement:** Caused by a high-alkaline solution that works into cracks in seams or improperly calked joints or rivets.

   Treatment: Maintain correct alkalinity levels in boiler-control blow-downs.

   Test: Alkalinity P, Alkalinity M

   Boiler-water limits: Alkalinity P – 250-300 ppm
   Alkalinity M – less than twice P

4. **Foaming and carryover:** Caused by high total dissolved solids, high alkalinity, or high surface tension.

   Treatment: Bottom blow-down to control solids and alkalinity.
   Surface blow-down to control or reduce high surface tension.

   Tests: Chlorides and conductivity-meter test

   Boiler-water limits: Chlorides 150-200 ppm
   T.D.S. 2000–2500 micromhos/cm

It should be noted here that the only reason for a buildup of scale in a boiler is *improper feedwater treatment.* No matter how bad your water is, with properly controlled treatment you should have no scale or corrosion.

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Procedure: After reading the information and listed references, answer the following questions.

Assignment:

1. What causes scale formation in a boiler?

2. What procedure would you follow if your boiler was foaming?

3. What are the recommended boiler-water limits for the following:

   a) Hardness
   b) Phosphate
   c) Alkalinity P
   d) Alkalinity M
   e) Chlorides
   f) Sulfite
   g) T.D.S.
   h) PH

Objective: Be able to explain how three different water-softening processes work.

Information: We already know that all raw water contains some amounts of scale-forming salts. We also know that scale will form in a boiler due to improper feed-water treatment. You will find water that will have to be treated externally (before it enters the boiler) and then treated internally, using your boiler chemical.

It is important to remember that when we treat our boiler feed-water, we are not destroying nor are we creating matter; we are only changing its chemical structure or makeup. As an example, water containing magnesium carbonate and calcium carbonate will form a hard scale. By adding caustic soda and phosphate, the magnesium carbonate becomes magnesium phosphate, and the calcium carbonate becomes calcium phosphate. Both of these are nonadhering sludges.

The larger your plant, the more elaborate your water-treatment system becomes. The zeolite water softener is one of the simplest methods of removing hardness from water. The zeolite, which is a granular material that is either mined or manufactured, has the ability to hold calcium carbonate, magnesium carbonate, and ferrous oxide (iron), and in this process it gives up its sodium ions.

After a quantity of hard water has passed over the zeolite, it will no longer have any sodium ions left to exchange for the calcium, magnesium, and iron ions. It will be much like a sponge that has absorbed all the water it can. In order for it to pick up more water, a sponge must be wrung out. In a zeolite softener, we call that regeneration. We pass a solution of common salt over the zeolite. This releases the calcium, magnesium, and any iron ions into the solution, so that they can be flushed away, and replaces them with sodium ions. Now the softener is ready to be put back into service.

Soda-lime softeners are usually found in larger plants. One type is a cold soda-lime treatment. This is a batch type of treatment at room temperature. The other is a hot soda-lime treatment, which is a continuous treatment which takes place at a temperature a little below steam temperature.

FULLY AUTOMATIC ZEOLITE WATER SOFTENER

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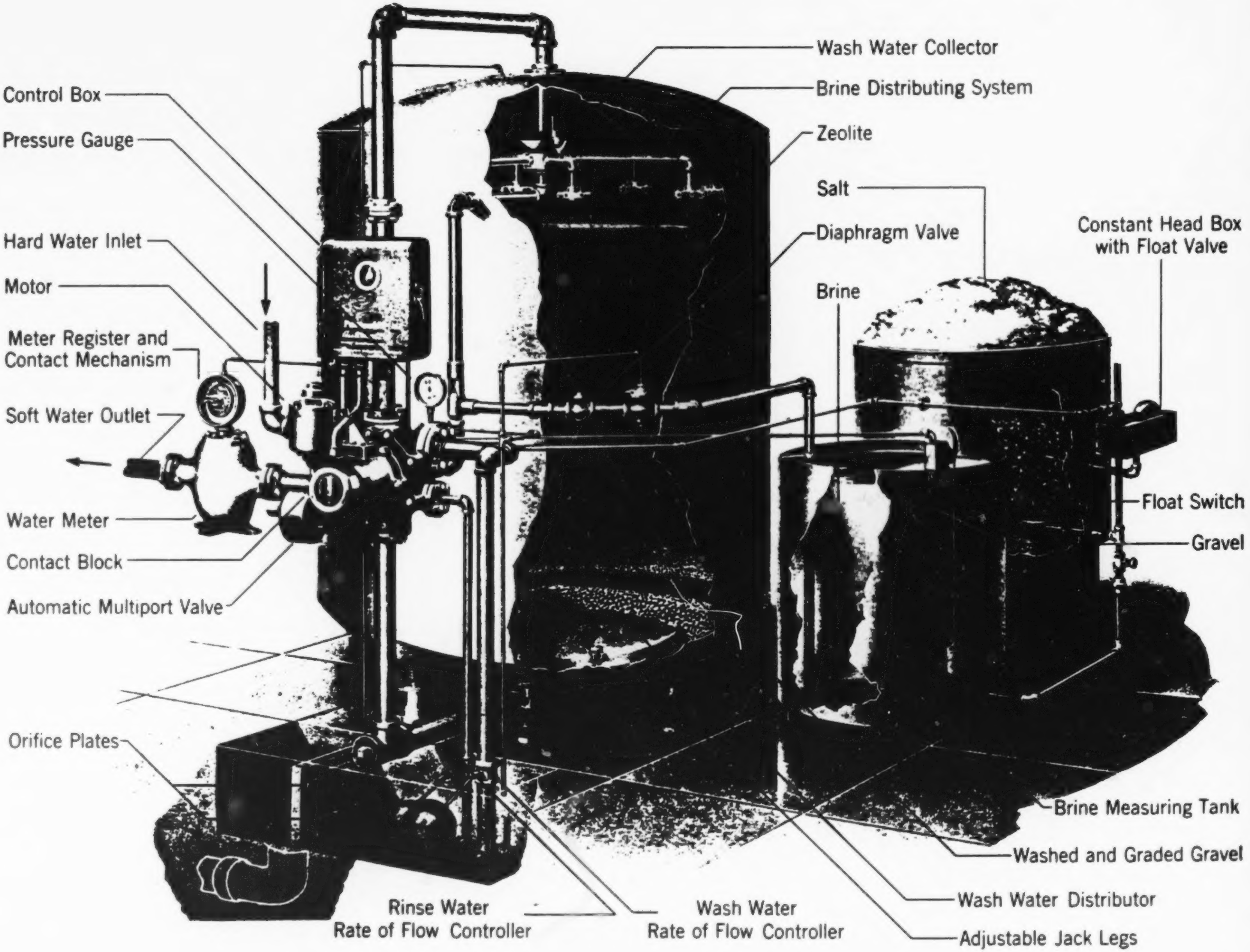
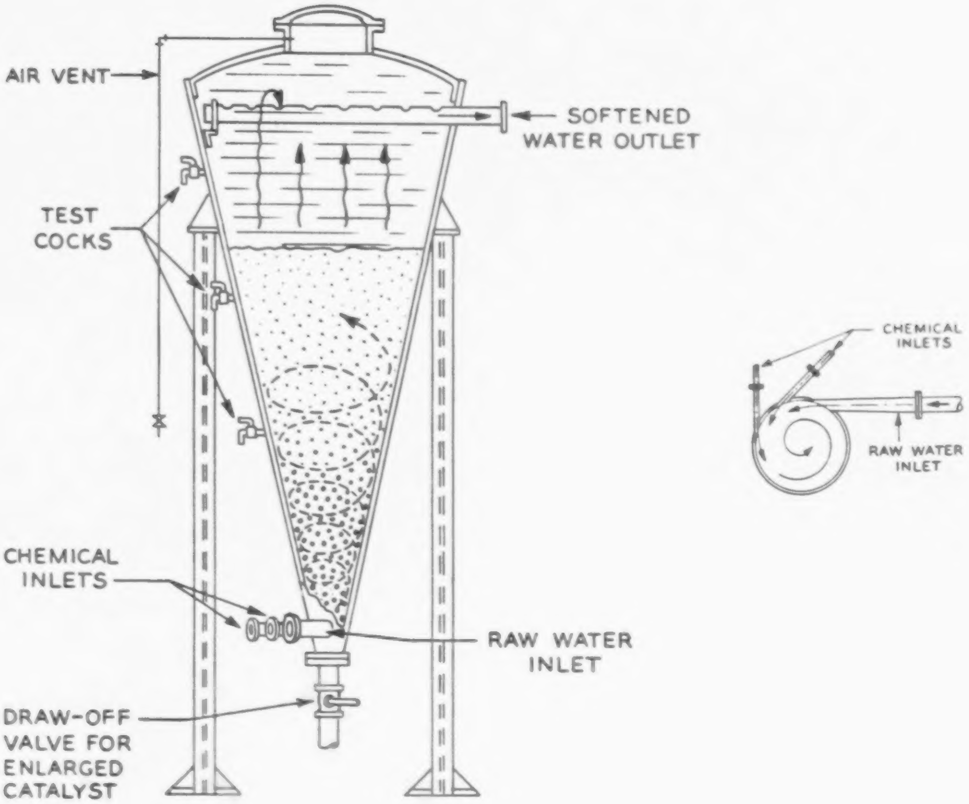
9-B-I-I

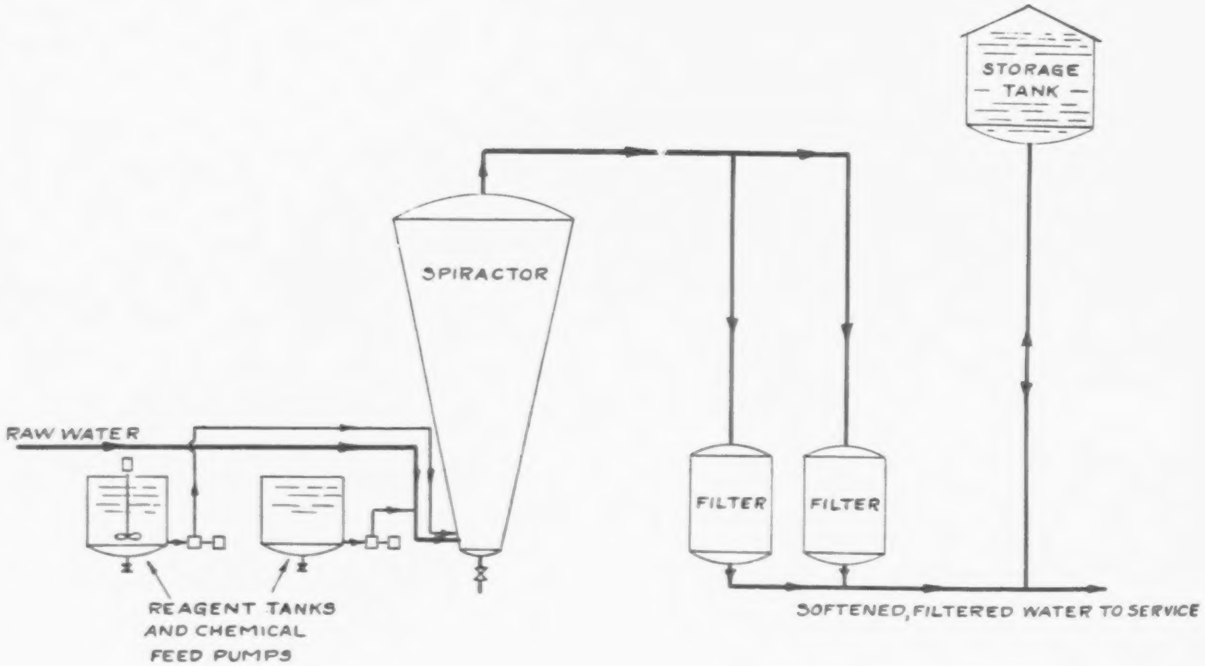

Wash Water Collector
Brine Distributing System
Zeolite
Salt
Diaphragm Valve
Constant Head Box with Float Valve
Brine
Control Box
Pressure Gauge
Hard Water Inlet
Motor
Meter Register and Contact Mechanism
Soft Water Outlet
Water Meter
Contact Block
Automatic Multiport Valve
Float Switch
Gravel
Orifice Plates
Brine Measuring Tank
Washed and Graded Gravel
Wash Water Distributor
Adjustable Jack Legs
Rinse Water Rate of Flow Controller
Wash Water Rate of Flow Controller


AIR VENT
SOFTENED WATER OUTLET
TEST COCKS
CHEMICAL INLETS
RAW WATER INLET
DRAW-OFF VALVE FOR ENLARGED CATALYST
CHEMICAL INLETS
RAW WATER INLET

COLD SODA-LIME WATER SOFTENER

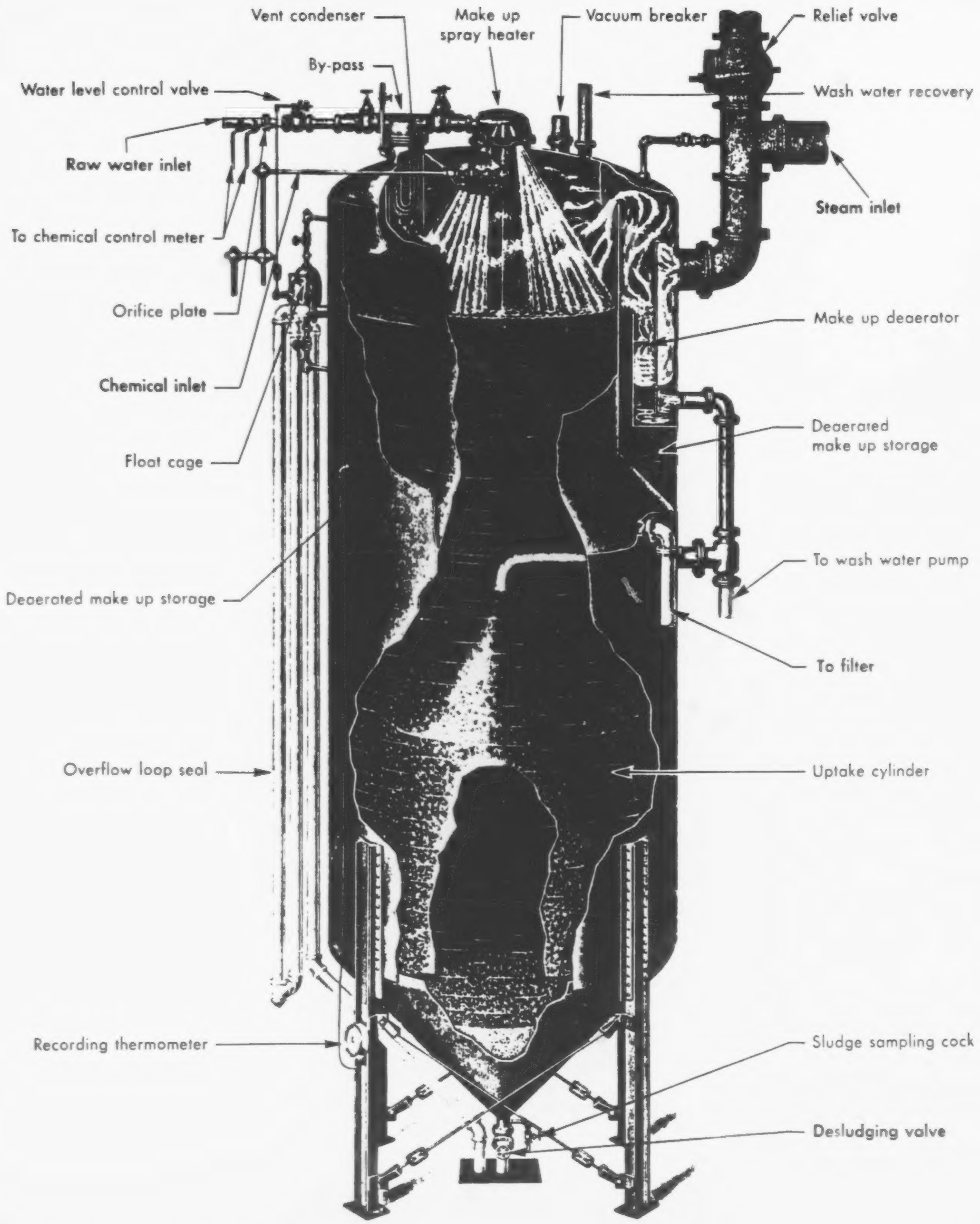
CROSS-SECTION VIEW OF SPIRACTOR, SHOWING FLOW

9-B-1-2

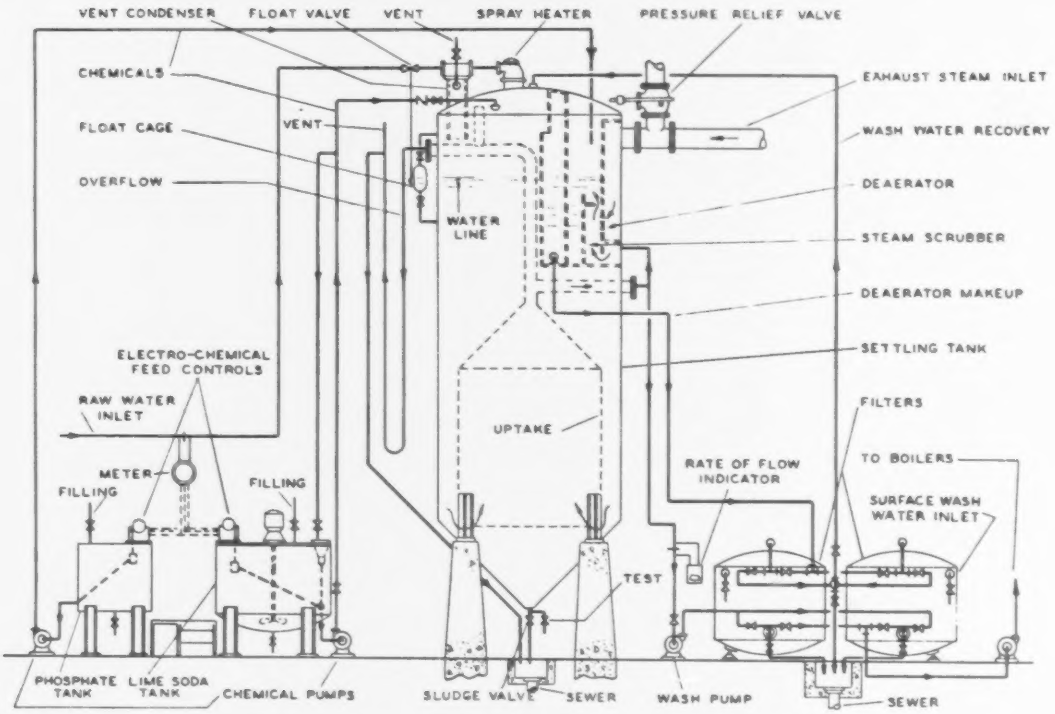

STORAGE TANK
SPIRACTOR
RAW WATER
FILTER
FILTER
REAGENT TANKS AND CHEMICAL FEED PUMPS
SOFTENED, FILTERED WATER TO SERVICE

FLOW DIAGRAM

COLD SODA-LIME SYSTEM


Vent condenser
Make up spray heater
Vacuum breaker
Relief valve
By-pass
Water level control valve
Wash water recovery
Raw water inlet
Steam inlet
To chemical control meter
Orifice plate
Make up deaerator
Chemical inlet
Deaerated make up storage
Float cage
To wash water pump
Deaerated make up storage
To filter
Overflow loop seal
Uptake cylinder
Recording thermometer
Sludge sampling cock
Desludging valve

HOT SODA-LIME WATER SOFTENER 9-B-1-4


VENT CONDENSER
FLOAT VALVE
VENT
SPRAY HEATER
PRESSURE RELIEF VALVE
CHEMICALS
EXHAUST STEAM INLET
FLOAT CAGE
VENT
WASH WATER RECOVERY
OVERFLOW
DEAERATOR
WATER LINE
STEAM SCRUBBER
DEAERATOR MAKEUP
ELECTRO-CHEMICAL FEED CONTROLS
SETTLING TANK
RAW WATER INLET
FILTERS
UPTAKE
METER
RATE OF FLOW INDICATOR
TO BOILERS
FILLING
FILLING
SURFACE WASH WATER INLET
TEST
PHOSPHATE TANK
LIME SODA TANK
CHEMICAL PUMPS
SLUDGE VALVE
SEWER
WASH PUMP
SEWER

FLOW DIAGRAM

HOT SODA-LIME SYSTEM

References: *Water Conditioning Hand Book*
Steam Plant Operation
Elementary Steam Power Engineering
Practical Power Service Library

Procedure: After reading the information and listed references, answer the following questions and be prepared to discuss each in class.

Assignment:

1. Describe in detail how a zeolite water softener works.
2. How do you go about regenerating a zeolite softener?
3. What precautions, if any, must be taken when back-washing?
4. Discuss in detail the cold soda-lime process of softening water.
5. Discuss in detail the hot soda-lime process of water softening.

Objectives: Be able to state the purpose and advantages of a continuous blow-down.

Be able to describe the location of a continuous blow-down line in the boiler.

Information: All boilers are equipped with some type of blow-down connections to remove sludge and sediment from the boiler. The bottom blow-down connection is designed for intermittent use, usually once in every 8- to 24-hour period.

Larger boilers, instead of using a batch method of chemical treatment and a bottom blow-down once to three times a day, use a continuous, proportioning type of chemical treatment with a continuously controlled blow-down. The advantge of this system is that, as you are forming solids in the boiler water with the chemical treatment, you are at the same time removing solids through the continuous blow-down.

The continuous blow-down connection is made at some point just below the low-water level in the steam-water drum. The discharge from the continuous blow-down line goes to the blow-down tank or to the flash tank. It is possible with this system to maintain a fairly constant total solids count in the boiler water.

It is still occasionally necessary to use the bottom blow-down, but it can be done when the boiler is off or on a light load, so that you remove a greater concentration of solid matter.

Reference: *Steam Plant Operation*
Elementary Steam Power Engineering

Procedure: After having studied the information and the listed references, answer the following questions.

Assignment:

1. What is the purpose of a continuous blow-down line?

2. Are all boilers equipped with continuous blow-down lines? Explain fully.

3. Where is the continuous blow-down line connected to a boiler?

4. What does the continuous blow-down line discharge to?

5. When will the bottom blow-down valves have to be used?

6. What are the advantages of using a continuous blow-down system?

Objective: Be able to describe how a flash tank functions.

Information: Boilers, as you know, have bottom blow-down valves, surface blow-down valves, and continuous blow-down valves. Usually the bottom blow-down and surface blow-down valves discharge into a blow-down tank and then go to waste. In order to reclaim the heat coming from your continuous blow-down, a flash tank is used.

You know that water at atmospheric pressure will boil at 212°F. If you increase the pressure you will raise the boiling point, and if you decrease the pressure you will lower the boiling point.

The water coming from the continuous blow-down is piped to the flash tank. As its pressure drops, the water flashes into steam. The steam is sent to the open feed-water heater. The city water line passes through coils below the water level in the flash tank, picking up heat. When the water level in the flash tank gets too high, an internal overflow will remove the water, and a trap will discharge it to waste.

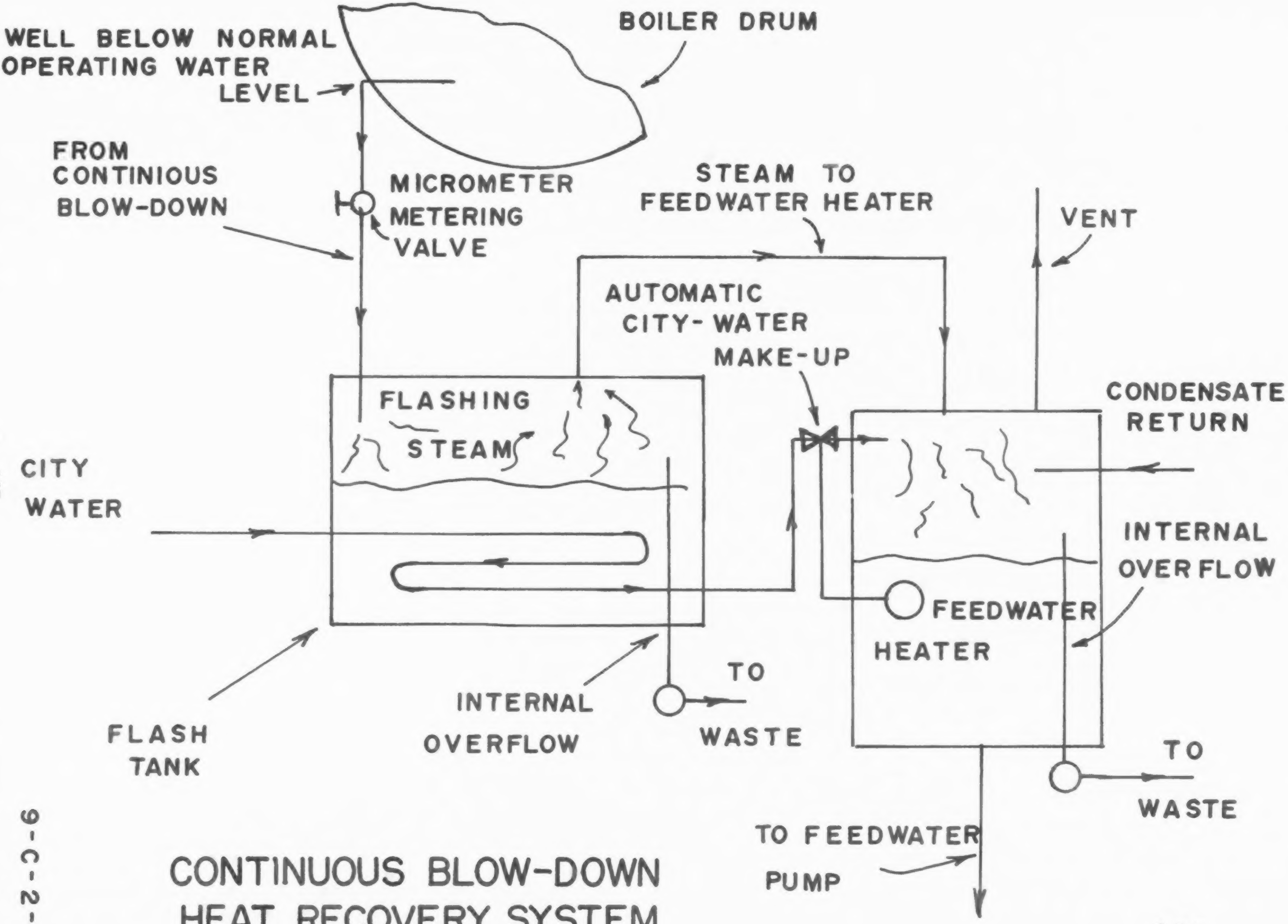
Remember, every 10°F. rise in feedwater temperature means about a 1% saving in fuel.

References: *Steam Plant Operation*
Elementary Steam Power Engineering
Practical Power Service Library

Procedure: After reading the information and listed references, answer the following questions and be prepared to discuss each in class.

Assignment:

1. Explain in detail why water coming from the continuous blow-off flashes into steam in the flash tank.
2. Why isn't the water in the flash tank reclaimed?
3. How is it possible to use this steam in the open feed-water heater? Isn't it contaminated?
4. Does using a continuous blow-down eliminate the need for a bottom blow-down? Explain your answer.


WELL BELOW NORMAL OPERATING WATER LEVEL
BOILER DRUM
FROM CONTINIOUS BLOW-DOWN
MICROMETER METERING VALVE
STEAM TO FEEDWATER HEATER
VENT
AUTOMATIC CITY-WATER MAKE-UP
FLASHING STEAM
CONDENSATE RETURN
CITY WATER
INTERNAL OVER FLOW
FEEDWATER HEATER
TO WASTE
INTERNAL OVERFLOW
FLASH TANK
TO WASTE
TO FEEDWATER PUMP

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9-C-2-1

CONTINUOUS BLOW-DOWN HEAT RECOVERY SYSTEM

Objectives: Be able to describe the construction of a DC generator.

Be able to describe the construction of an AC generator.

Information: A direct current (DC) generator consists of the following parts:

1. a frame
2. an armature
3. a commutator
4. set of brushes
5. field poles

The **frame** is circular in shape and holds the field poles in place. It is usually of iron or steel construction.

The **armature** is made up of a soft-iron laminated core with coils inserted around the core. The ends of the coils are connected to the commutator.

The **commutator** is made up of copper segments and is fastened to the armature by clamping rings. The **commutator brushes** carry the electrical energy from the commutator to the external circuit.

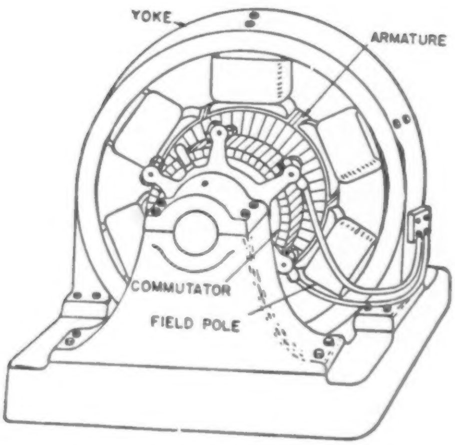
The **field pole** consists of a laminated steel core wound with insulated copper wire and fitted into the frame of the generator.

In the DC generator the armature, supported by bearings, rotates within the stationary field poles. The brushes are mounted on brush holders with springs to maintain proper tension, and make contact with the commutator.

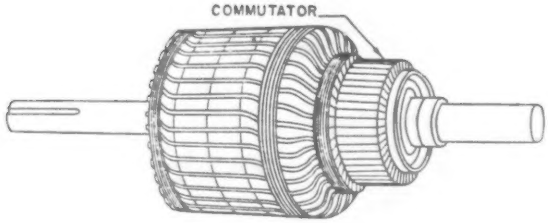
An alternating current (AC) generator consists of the following parts:

1. a frame
2. a rotor
3. slip rings
4. a stator

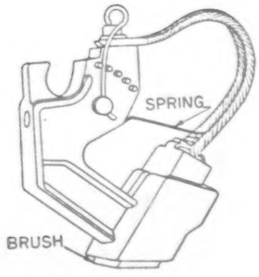
The **frame** is circular in shape and holds the stator, or stationary armature, in place.


YOKE
ARMATURE
COMMUTATOR
FIELD POLE

D.C. GENERATOR


COMMUTATOR

ARMATURE


SPRING
BRUSH

BRUSH HOLDER

The **stator** is made up of a core with coils spaced evenly around the core.

The **rotor**, or revolving field, consists of a laminated core with coils of wire wound around the edges. A fan is mounted on one end of the rotor to remove heat from the coils. At the end of the rotor are the **slip rings**. These rings are connected to the ends of the field coils and are used to excite or energize the field coils.

In the AC generator, the rotor with its field windings rotates within the stator (stationary armature), supported by bearings. The power produced by the generator is removed by way of the stator leads.

Both AC and DC generators are excited by DC. Some DC generators are self-exciting and therefore do not need a separate source of DC for excitation.

Both generators actually produce an alternating current, but the commutator and brushes on the DC machine act as a rectifier to give a DC pattern.

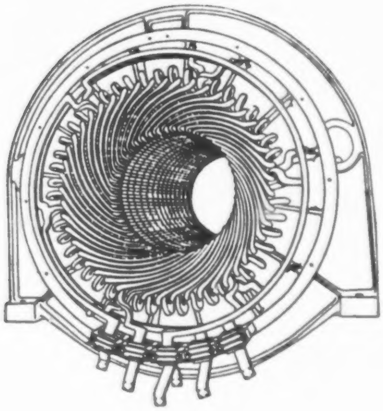
AC machines are usually smaller in size than DC machines for a given output. They also tend to have higher output voltages, which makes the electricity easier to transmit.

Reference: *D.C. Fundamentals*
A.C. Fundamentals

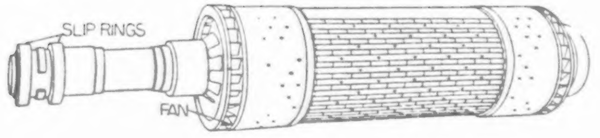
Procedure: After studying the information and the reference, answer the following questions.

Assignment:

1. List the names of the parts of a DC generator and describe each part.
2. List the names of the parts of an AC generator and describe each part.
3. Make a comparison between the DC and AC generators.



A. C. GENERATOR STATOR


SLIP RINGS
FAN

A.C. GENERATOR ROTOR

Objective: Be able to determine the frequency of an AC generator.

Information: The frequency generated by an alternating-current generator depends upon its speed and the number of poles it contains.

$$\text{Frequency} = \frac{\text{No. of poles} \times \text{RPM}}{120}$$

$$f = \frac{P \times N}{120}$$

Where f = frequency in cycles per second
P = number of magnetic poles in the generator
N = revolutions per minute of the generator

Example 1: Find the frequency of a generator that is turning at 3600 RPM and has two poles.

$$f = \frac{P \times N}{120}$$

$$= \frac{2 \times 3600}{120} = 60 \text{ cycles per sec.}$$

Example 2: How many poles does an AC generator have that runs at 60 cycles per second at a speed of 3600 RPM?

$$f = \frac{P \times N}{120}$$

$$P = \frac{120 \times f}{N}$$

$$= \frac{120 \times 60}{3600} = 2$$

Reference: *Industrial Electricity*

Procedure: After studying the above information and reference, do the following assignment.

Assignment:

1. An AC generator has a frequency of 60 cycles per second. How fast is it running if it has —
   - a. 2 poles
   - b. 4 poles
   - c. 8 poles

2. If you walked into a strange generating plant, how would you know how many poles its AC generator had?

3. What would be the effect in problem 1 if the frequency was changed to 30 cycles per second?

Objectives: Be able to state the purpose of a voltage regulator.

Be able to state the purpose of a synchroscope.

Be able to name the different types of AC and DC meters and tell their purposes.

Be able to explain how to parallel two AC or two DC generators.

Information: A **voltage regulator's** function is to maintain a fairly constant terminal voltage on an AC generator. It does this by increasing or decreasing the field current to the generator. An increase in field current will increase the terminal voltage, while a decrease will lower the voltage. Most voltage regulators in use today function automatically.

Several types of meters are found in a generating plant. A **synchroscope** is a meter that will show the phase relationship between two voltages. It is used when two AC generators are paralleled or put in synchronization. **Voltage meters** are used to give you a terminal voltage reading, AC or DC. An **ammeter** gives you the flow of electrons, or current. This is a very important meter because it shows you the load.

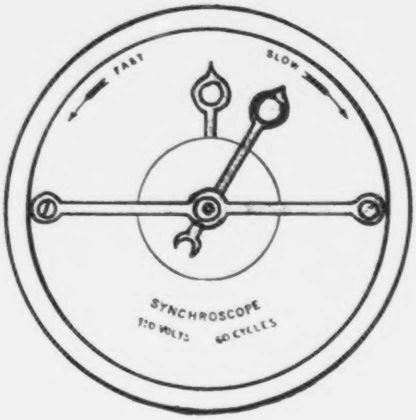
To parallel two A.C. generators, the following conditions must be met:

1. Terminal voltage of the generators must be the same.
2. Frequency of the generators must be the same.
3. The voltages of the generators must be in phase.

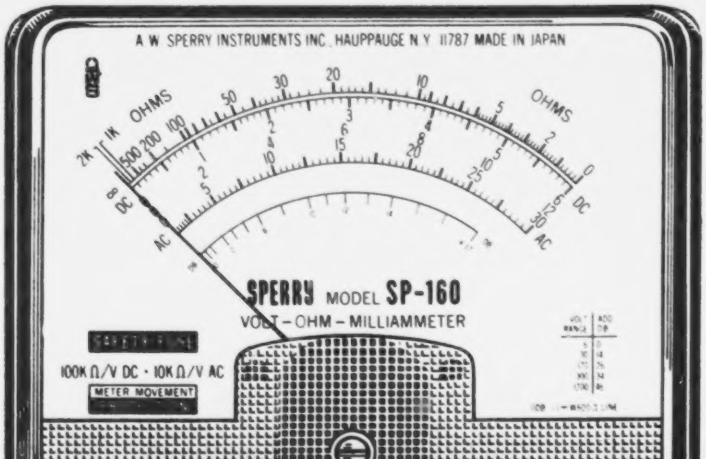
When the conditions outlined above are met, you can close the main breaker.

It is sometimes necessary to parallel D.C. generators. An example would be when changing over a motor/generator set. It is done in the following manner:

1. Bring up generator to its rated voltage.
2. Close the negative and the equalizer switches.
3. Adjust the voltage to equal that of bus line.
4. Close positive switch.


FAST
SLOW
SYNCHROSCOPE
120 VOLTS
60 CYCLES

SYNCHROSCOPE


A.W. SPERRY INSTRUMENTS INC. HAUPPAUGE N.Y. 11787 MADE IN JAPAN
OHMS
OHMS
DC
AC
DC
AC
SPERRY MODEL SP-160
VOLT-OHM-MILLIAMMETER
100K Ω/V DC · 10K Ω/V AC
METER MOVEMENT

VOLT-OHM MILLIAMMETER

Both AC and DC generators should be put under load of at least 20 percent of their rated capacities. On AC generators this is done by increasing the speed slightly. The DC generator is loaded by increasing the field current.

References: *Industrial Electricity*
A.C. Fundamentals
D.C. Fundamentals

Procedure: After studying the information and the listed references, complete the following assignment.

Assignment:

1. What is the purpose of a voltage regulator?
2. What is the purpose of a synchroscope?
3. What types of meters are used in a generating plant? What are they used for?
4. How are two AC generators paralleled?
5. How are two DC generators paralleled?
6. How do you apply load to an AC generator?
7. How do you apply load to a DC generator?

Objectives: Be able to describe how electrical power is distributed in a generating power plant.

Be able to describe a transformer and explain how it works.

Information: AC electrical power is usually generated at 2200 to 2300 volts in a generating process plant. The heavy electrical equipment, such as motors for running compressors, coal mills, forced- and induced-draft fans, feed-water pumps, and motor-generator sets, are run on high voltage and are confined to the power-plant area.

For distribution purposes and safety, the voltage is stepped down before going out for process use. A device called a **transformer**, simple and rugged in construction and without moving parts, steps the voltage down with only a very small loss. The stepped-down voltage is usually 440V and 220V for process motors and 110 volts for lighting and control circuits.

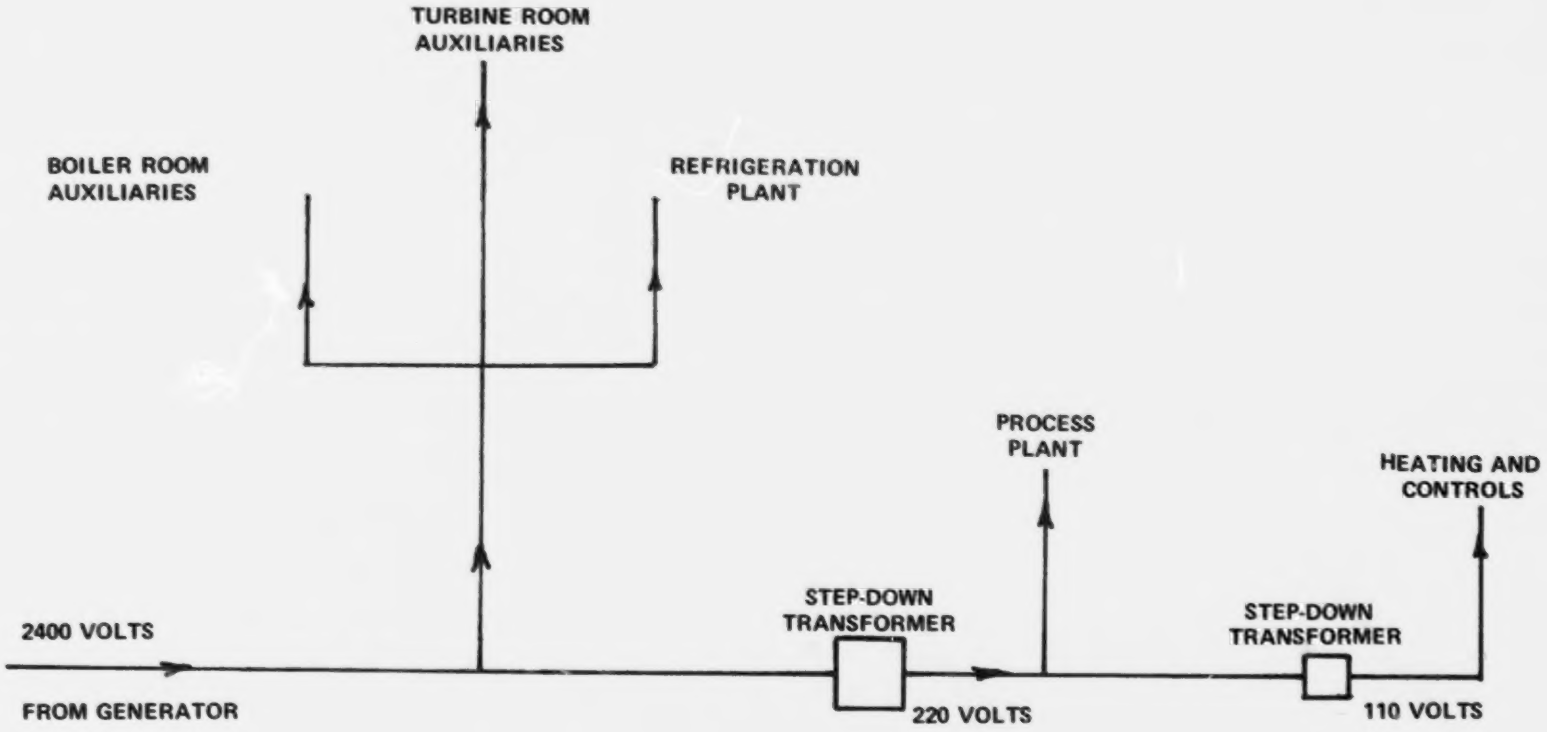
The transformer consists of two coils on an iron core. When an AC current is supplied to one coil (the primary), a magnetic field is produced. The field makes and breaks across the second coil, inducing a voltage in it. The ratio of the two voltages is directly proportional to the number of turns on the two coils.

References: *Industrial Electricity*
A.C. Fundamentals

Procedure: After studying the above information and the listed references, complete the following assignment.

Assignment:

1. What voltages are common in a generating process plant?
2. Explain where the various voltages are used in the plant.
3. Why is a transformer such a useful piece of equipment?
4. Describe a transformer in detail.
5. How does a transformer function?
6. With a line drawing, show the basic distribution of power in a generating process plant.



TURBINE ROOM AUXILIARIES

BOILER ROOM AUXILIARIES

REFRIGERATION PLANT

PROCESS PLANT

HEATING AND CONTROLS

STEP-DOWN TRANSFORMER

STEP-DOWN TRANSFORMER

2400 VOLTS

FROM GENERATOR

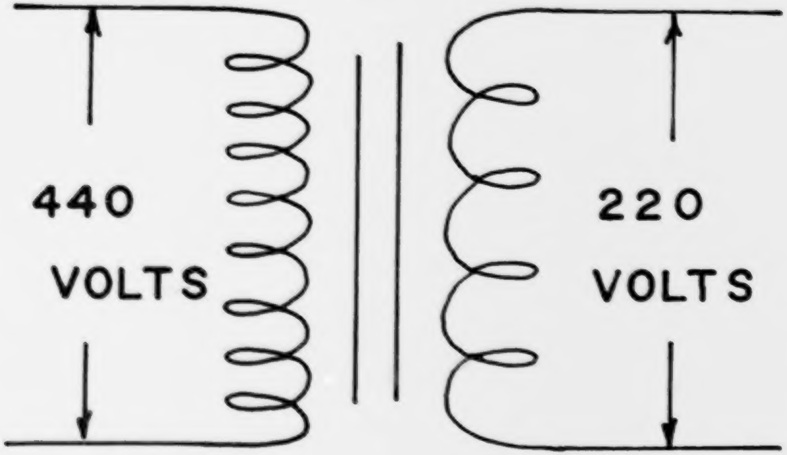
220 VOLTS

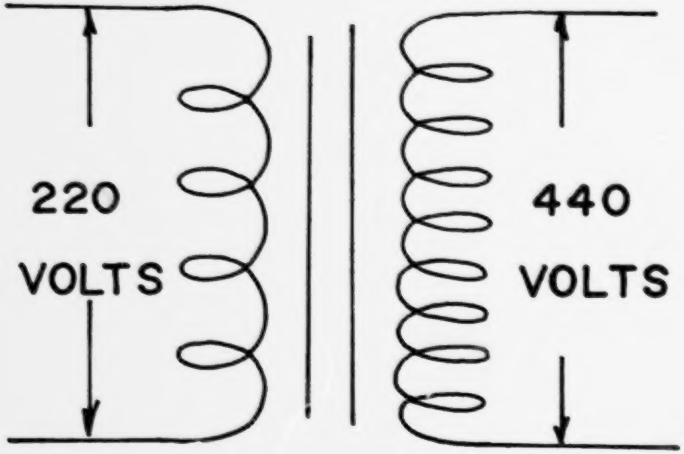
110 VOLTS

GENERATING PROCESS PLANT ELECTRIC DISTRIBUTION LOAD

10-C-1-1

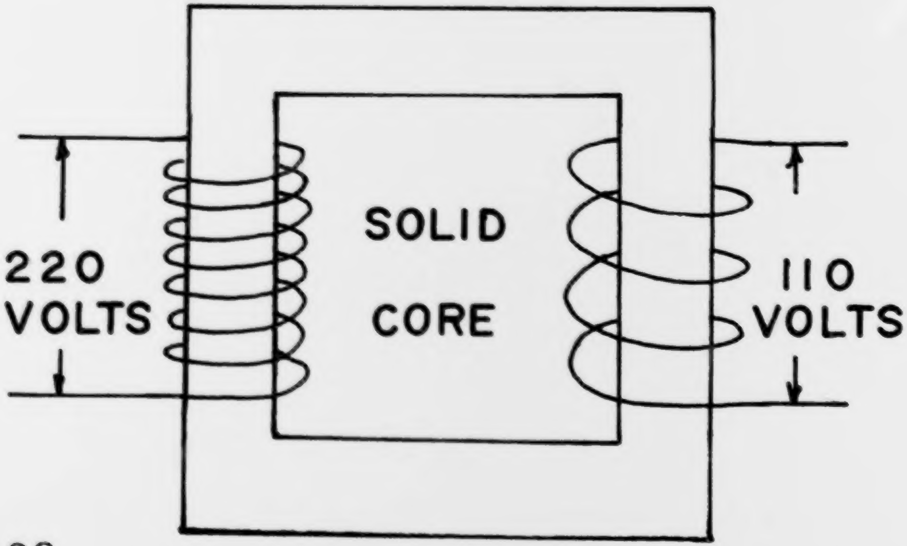
STEP-DOWN TRANSFORMER


440
VOLTS
220
VOLTS


220
VOLTS
440
VOLTS

STEP - UP TRANSFORMER

179


220
VOLTS
SOLID
CORE
110
VOLTS

SOLID-CORE TRANSFORMER

10-C-1-2

199

200

Objective: Be able to describe a motor-generator set and explain its use in a generating process plant.

Information: Generating process plants usually generate alternating current. It is much easier to distribute, and the voltage can be stepped down by using transformers. The use of direct current in these plants is seldom eliminated completely, hence the need for motor-generator sets.

The motor-generator set consists of an alternating-current motor that runs off of line voltage and turns a direct-current generator. In this way there is enough DC power to operate elevators, excite any synchronous motors, charge batteries, and supply a DC circuit for control switches.

The motor-generator requires the following attention:

1. Maintain proper lubrication of the bearings.
2. Check for any arcing between the commutator and brushes.
3. Adjust for field excitation to maintain correct terminal voltage.

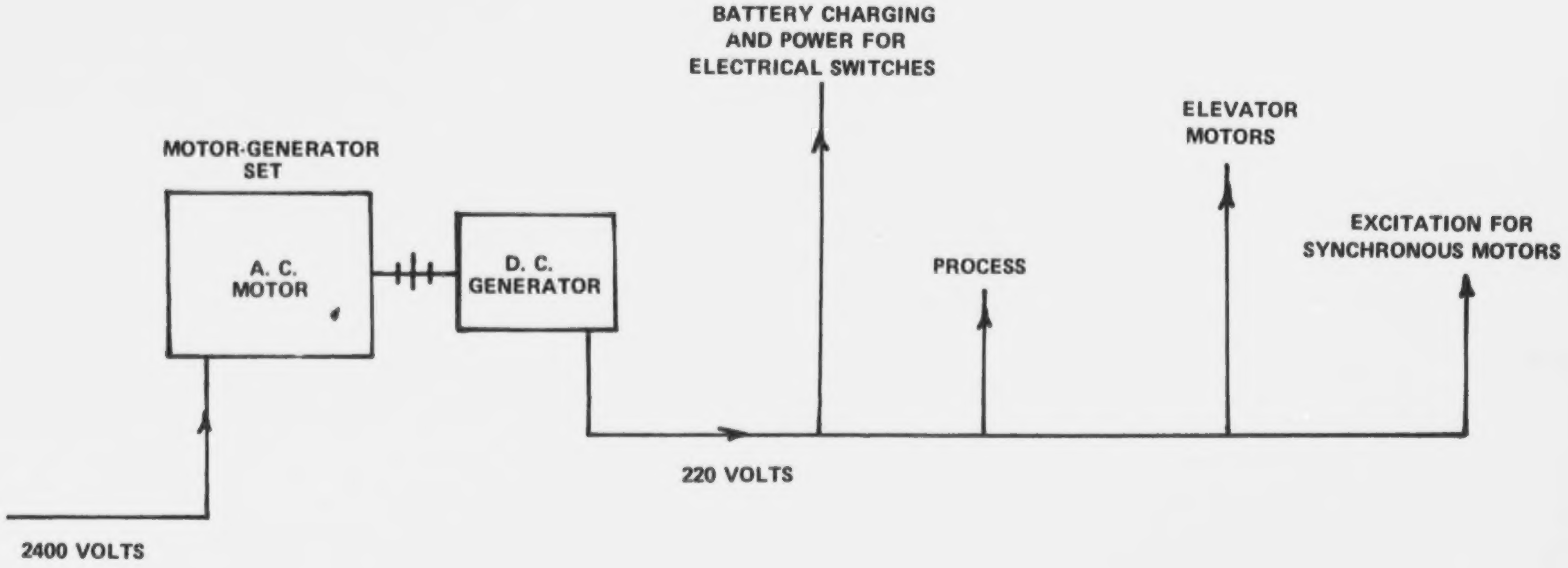
Most plants will have two M-G sets that are changed over once a month. When changing over, you have to parallel the incoming with the other generator, apply the load, and then remove the other generator from service.

Reference: *Industrial Electricity*

Procedure: After studying the above information and the reference, complete the following assignment.

Assignment:

1. Describe a motor-generator set.
2. What is the purpose of a motor-generator set?
3. What attention does a motor-generator set require?
4. How do you change over a motor-generator set?
5. What equipment needs DC voltage in a modern plant?



MOTOR-GENERATOR SET

A. C. MOTOR

D. C. GENERATOR

2400 VOLTS

220 VOLTS

BATTERY CHARGING AND POWER FOR ELECTRICAL SWITCHES

PROCESS

ELEVATOR MOTORS

EXCITATION FOR SYNCHRONOUS MOTORS

10-C-2-1

D.C. POWER DISTRIBUTION IN PROCESS PLANTS

202

203

Reciprocating Pump — Review of Theory of Operation

Assignment 11—A—1

Objective: Be able to explain the procedure in starting a reciprocating pump.

Information: A reciprocating pump is a positive-displacement pump. If it is to be used as a boiler-feed pump, its steam side must be 2 to 2½ times larger in area than its liquid side. This is so it can develop enough pressure to overcome the boiler pressure. If the liquid end were larger, the pump could be used as a transfer pump only. That means it would handle volume but not build up a high pressure. The name-plate data states:

1st — diameter of steam cylinder
2nd — diameter of liquid cylinder
3rd — length of stroke

All dimensions are in inches.

With a positive-displacement pump, the discharge valve must be opened before attempting to start the pump. Perhaps this would be a good time to go over a startup procedure:

1. Open all drains on steam side of pump.
2. Open exhaust valve.
3. While pump is warming up, examine pump for rags, tools, or loose parts.
4. Check lubrication.
5. Open discharge and suction valves.
6. Drain steam line to pump.
7. Crack steam valve and allow pump to make a few slow strokes to clear steam cylinder of any condensate.
8. When no evidence of condensate is coming out of drains — secure drains.
9. Slowly open steam valve wide and watch to make sure pump governor takes over.

It is most important that, when you secure the pump, the steam and exhaust valves be closed, and also the suction and discharge valves. All drains on the steam side must be open.

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Procedure: After reading the information and references, answer the following questions and be prepared to discuss each in class.

Assignment:

1. Why is it a good idea to warm up the steam cylinders with exhaust steam?
2. Why is it important to completely drain all condensate from the steam cylinders?
3. How is a positive-displacement pump protected from excessive pressure on the discharge side?
4. Why is it necessary for the steam side to be larger in area than the water side of a reciprocating feed-water pump?
5. Describe in detail the procedure you would follow in starting a reciprocating pump, and explain why each step is taken.

Objectives: Be able to properly secure a reciprocating pump.

Be able to place the pump in mid-position.

Be able to set the valves.

Information: Before the valves can be set, the pump must be placed in mid-position. To do this you would proceed as follows:

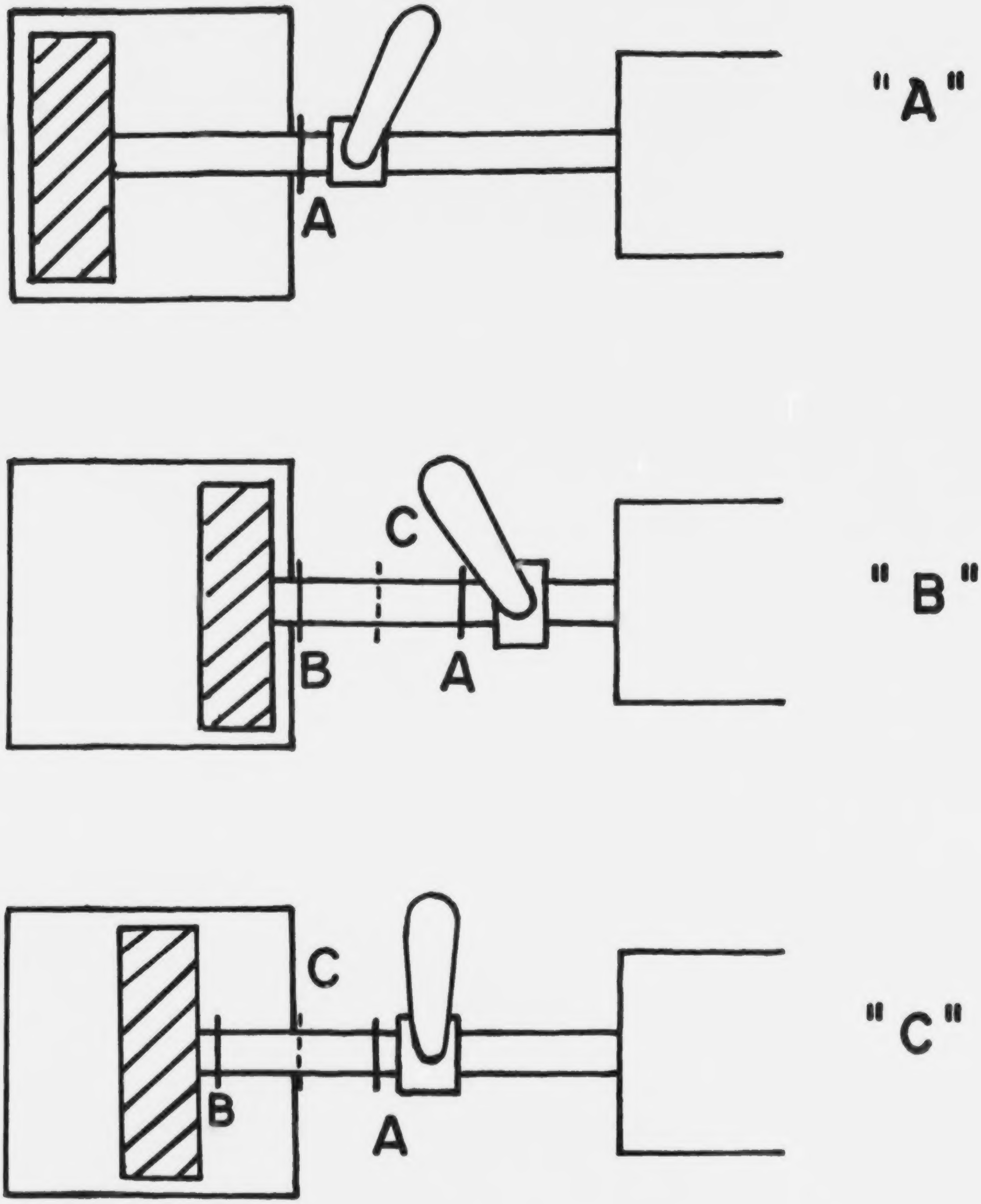
1. Secure steam and exhaust suction and discharge valves (4 valves in all).
2. Open drains on both steam and water sides.
3. Bar pump toward steam side as far as it will go.
4. Scribe a mark on steam piston rod flush with packing gland.
5. Bar pump in opposite direction as far as it will go. Mark steam rod again, flush with packing gland.
6. With dividers, find center between the two marks. Mark rod.
7. Bar pump toward steam side, lining the last mark flush with packing gland.
8. Rocker arm should be perpendicular to steam piston rod. One side of pump is now in mid-position.

Follow same procedure on other side of pump. Pump is now ready to have the valves set. NOTE: When barring pump over, bar it against crosshead or spool piece, never against rocker arm.

Now, with the pump in mid-position, we shall proceed to set the valves.

1. Mark and remove the valve chest cover.
2. Move the slide valve so that it covers all ports.
3. Move valve in one direction as far as it will go. Measure port opening.
4. Move valve in opposite direction as far as it will go. Measure port opening.

NOTE: Steam port openings should be equal, with about one-half of a port open on each side when the D–slide is at its end position. This distance is known as lost motion (See sketch 11–A–2–2). The lost motion allows the pump to make a full stroke, and it also prevents the pump from striking the head. After setting the lost-motion nut, move one valve to uncover a port, otherwise the pump cannot start. Once in motion, the duplex reciprocating pump can never stop with all the ports covered.


"A"
A
C
"B"
B
A
C
"C"
B
A

SETTING MID-POSITION

5. Make new gasket for valve chest cover.
6. Replace cover and test pump.

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Procedure: After reading the information and studying the sketches and references, answer the following questions and be prepared to discuss each in class.

Assignment:

1. Why is it necessary to secure steam and exhaust suction and discharge valves on pump before barring it over?

2. Why do the drains have to be open on both steam and water sides of pump?

3. Why should you bar over the pump against the crosshead and not against the rocker arm?

4. Show by sketch how you would mark the pump when putting it in mid-position.

5. What is meant by lost motion?

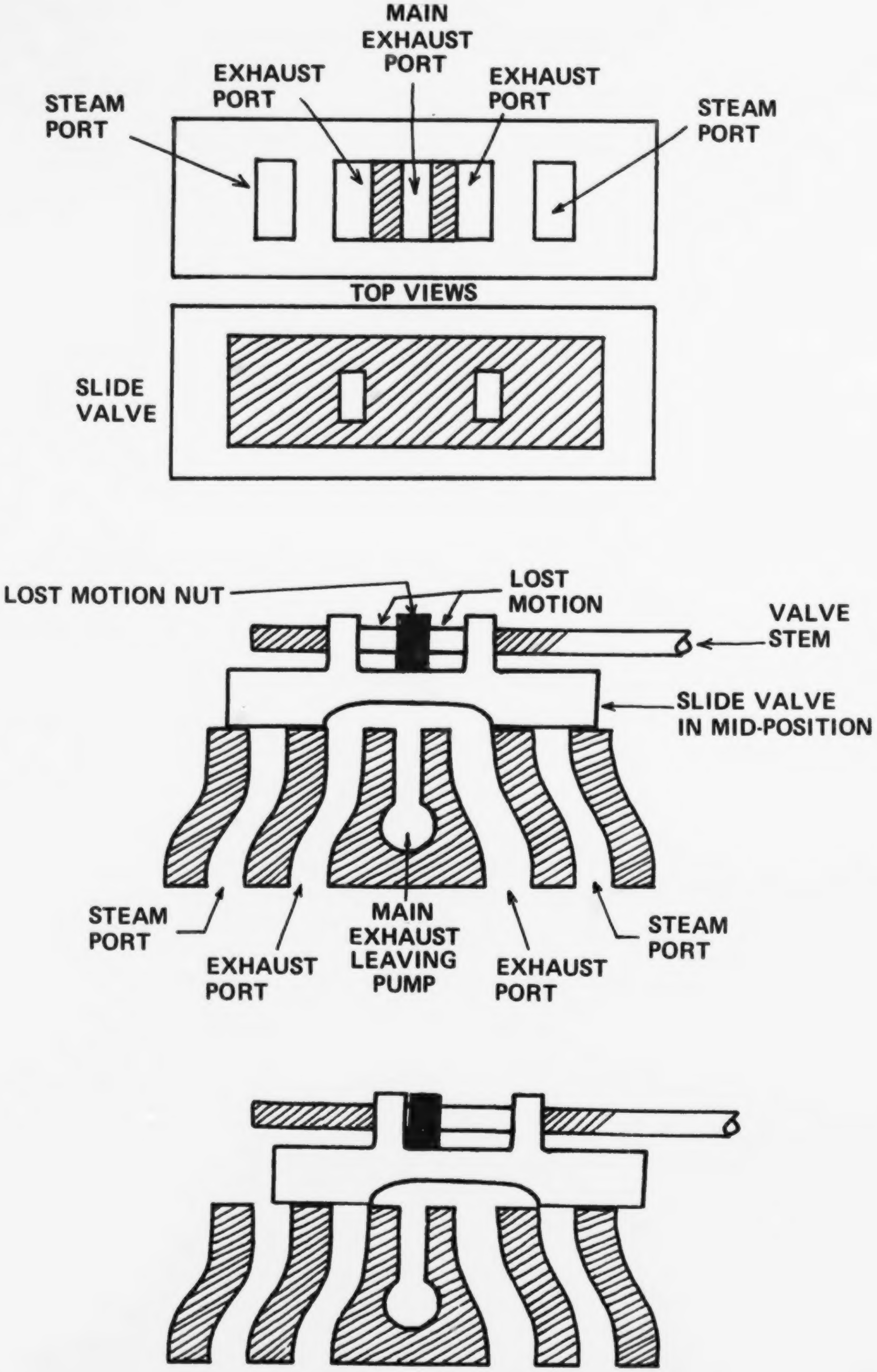
6. What happens if a pump has too little lost motion? Too much lost motion?

7. What prevents the steam piston from striking the head?

8. How does a pump's short-stroking affect the steam consumption?

9. Describe how you would set the valves on a duplex pump.

10. Do steam valves on a duplex pump have lap or lead? Explain fully.


MAIN EXHAUST PORT
EXHAUST PORT
EXHAUST PORT
STEAM PORT
STEAM PORT
TOP VIEWS
SLIDE VALVE
LOST MOTION NUT
LOST MOTION
VALVE STEM
SLIDE VALVE IN MID-POSITION
STEAM PORT
EXHAUST PORT
MAIN EXHAUST LEAVING PUMP
EXHAUST PORT
STEAM PORT

VALVE CHEST, DUPLEX PUMP
SHOWING D-SLIDE VALVE AND PORT OPENINGS

Centrifugal Pump — Review of Theory of Operation

Assignment 11—B—1

Objective: Be able to describe the operation of five types of centrifugal pumps.

Information: In our first-year manual we discussed the theory of operation, purpose, and location and parts of a centrifugal pump. In our second-year manual we discussed the advantages and disadvantages of centrifugal pumps. Let's just review a few highlights.

All centrifugal pumps work on the principle that centrifugal force builds up kinetic energy, and kinetic energy will overcome the potential energy of the boiler. The five major types of centrifugal pumps are:

1. Volute
2. Diffuser
3. Mixed-flow
4. Axial-flow
5. Turbine

With the first four pumps, the discharge valve must be closed in order to build up pressure when starting. With the turbine-type centrifugal pump, the tolerances are very close, and the discharge valve must be open when starting up the pump. It must also be fitted with a relief valve between the pump and the discharge valve. By adding stages, the discharge pressure can be built up to the required pressure.

References: *Science Manual 1*
Science Manual 2
Steam Plant Operation
Elementary Steam Power Engineering

Procedure: After studying the references, answer the following questions and be prepared to discuss each in class.

Assignment:

1. Briefly describe the five major types of centrifugal pumps.

2. How does the turbine pump differ from the other four types?

3. What are the advantages of using a centrifugal pump? the disadvantages?

4. Can a centrifugal pump become steam-bound?

5. Why must the discharge valve on a turbine-type pump be open, and on the other four types be closed when starting?

Centrifugal Pumps — Functional Failure   Assignment 11–B–2

Objectives: Be able to suggest solutions to three different pump problems.

State the precautions to be taken to keep a centrifugal pump trouble-free.

Information: Centrifugal pumps have been taking the place of reciprocating pumps because of their simplicity of operation and adaptability to electric or steam drive. As it gets older, its efficiency remains pretty much the same, because there are no valves or plungers or rings to wear. Now that doesn't mean it is completely trouble-free. It can still have problems. Let's just look at some.

If you use a turbine drive, you must make sure your governor linkage is free, and the governor operates to maintain a steady RPM. A faulty governor could destroy the turbine. You must also test the overspeed trip when you start the turbine and when you stop the turbine.

Packing on all pumps must be inspected daily. You must make sure the glands are taken up evenly. A cocked gland can damage your rod. There should always be a slight drip, to keep the packing lubricated. It is also important to check the coupling alinement. If your coupling is cocked it will cause a strain on your shaft. Bearing lubrication must be watched to prevent wear. Overlubrication is just as bad as underlubrication.

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Procedure: After reading the information and studying the listed references, answer the following questions and be prepared to discuss each in class.

Assignment:

1. Discuss what might be the trouble in the following situations:
   a) Pump is not delivering water.
   b) Pump is not delivering enough water.
   c) Pump is not putting out enough pressure.

2. What factors must be considered when installing a pump so that it will give trouble-free operation?

Objective: Be able to state the factors to consider when selecting a pump.

Information: The centrifugal pump has become very popular because it has few moving parts and can be easily adapted to electric or steam drive. When selecting a centrifugal pump you should contact the manufacturer and explain what type of service the pump is to be used for. The manufacturer will recommend the proper pump. You certainly would not use the same pump to pump slurry as you would to pump feed-water.

When selecting a boiler feed pump, you must consider the following:

1. Amount of water needed (should be about 50 pounds of water per boiler horsepower).
2. Discharge pressure required.

Note: If your plant is burning coal, you should have at least one steam- and one electric-drive pump.

References: *Steam Plant Operation*
Elementary Steam Power Engineering
Pump Questions and Answers

Procedure: After reading the information and studying the listed references, answer the following questions and be prepared to discuss each in class.

Assignment:

1. Why is the centrifugal boiler feed pump always located below the open feed-water heater?

2. What factors must be considered when selecting a boiler feed pump?

3. Why is it necessary to have one steam and one electric feed-water pump if you are burning coal?

Objectives: Be able to define the terminology connected with steam turbines.

Be able to describe the various types of turbines.

Information: The history of the turbine goes back to about 120 B.C., when an Egyptian by the name of Hero developed the first reaction turbine (Fig. 12-A-1-1). Then in 1629 an Italian scientist Giovanni di Branca designed the first impulse turbine (Fig. 12-A-1-2). It consisted of a bust filled with water, with a fire built under it. The steam that was built up inside the bust was directed against vanes which through gears caused two plungers to move up and down and grind or pulverize his chemicals. It was not very efficient, but it did work.

The development of the modern turbine was slowed by the lack of metals and other materials capable of withstanding the tremendous stresses set up by high speeds and the enormous temperature changes. It wasn't until the late 1800's that the first real breakthrough was made. From then till today remarkable advancements have been made.

The turbines of 1920 used steam at about 325 p.s.i. By 1940 the steam pressure had risen to 1300 p.s.i. and to 2300 pounds in 1941. In 1979 we have pressures as high as 2800 p.s.i. A typical modern turbine may be 20 feet long with the steam at 1200 p.s.i. and a 900°F. temperature. At that temperature the metal will glow a dull red. Then in about 1/30 of a second the steam will be exhausting into a 28" vacuum at a temperature of about 70°F. You can see now why it took so long to develop metals to stand up to these conditions.

Before we can study about turbines, we must first become familiar with some definitions. Let's first define a turbine: It is a prime mover in which steam at high velocity hits the blades of a rotating element, thereby transforming the kinetic energy of steam into mechanical work. In a turbine it is the velocity and the heat energy of the steam that are transformed into mechanical work.

Definitions of the Principles and Mechanics Involved in Turbine Operation

Work: Result of a force acting through space
Power: Rate at which work is done
Energy: Ability to work
Kinetic Energy: Energy of motion

Potential Energy: Energy of position

Heat Energy: Due to molecular motion and may be considered a type of kinetic energy

Classes of turbines: Turbines are divided into two general classes: impulse and reaction, according to the method by which the steam imparts its energy.

Impulse: Force acting in a forward direction

Reaction: An equal force acting in the opposite direction

Impulse Turbine: Expansion of steam completed within the nozzle only

Reaction Turbine: Expansion of steam takes place within a set of stationary and moving blades.

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Procedure: After reading the listed references, answer the following questions and be prepared to discuss each in class.

Assignment:

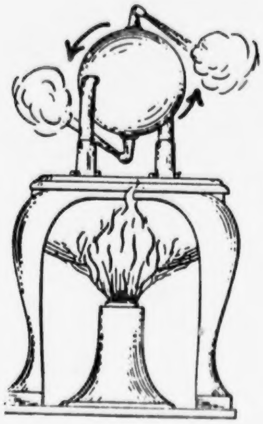
1. Why did it take so long to develop the steam turbine?

2. If a turbine uses steam at 1200 p.s.i. and 900°F., what is the condition of the metal at the turbine nozzle?

3. How are turbines classified?

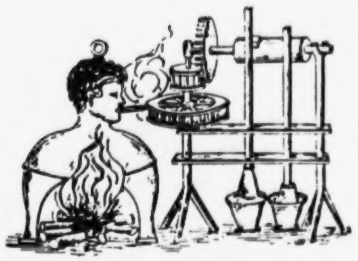
4. a) Define work
   b) Define power
   c) Define energy
   d) Define kinetic energy
   e) Define potential energy
   f) Define impulse
   g) Define reaction

5. Briefly describe the following turbines:
   a) straight condensing
   b) straight non-condensing
   c) extraction
   d) induction (or mixed pressure)
   e) induction-extraction



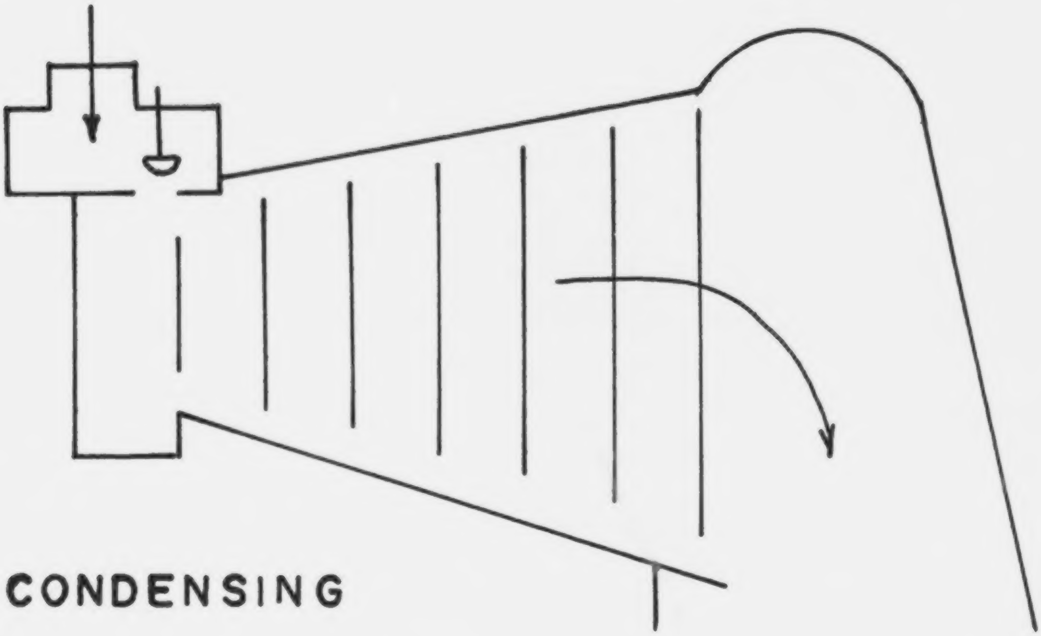
HERO'S REACTION TURBINE

12-A-1-1



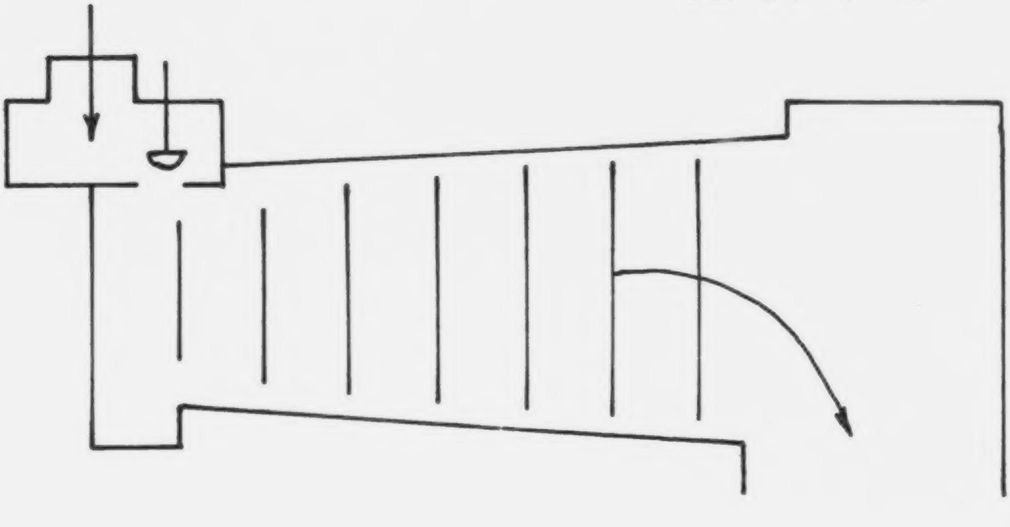
DIBRANCA'S IMPULSE TURBINE

12-A-1-2



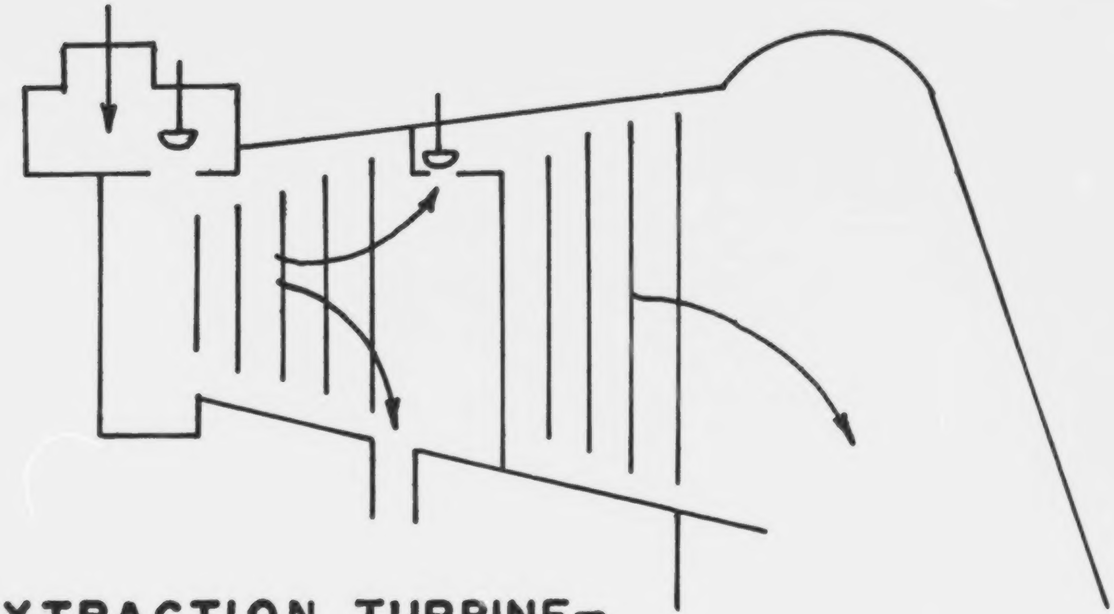
CONDENSING

12-A-1-3



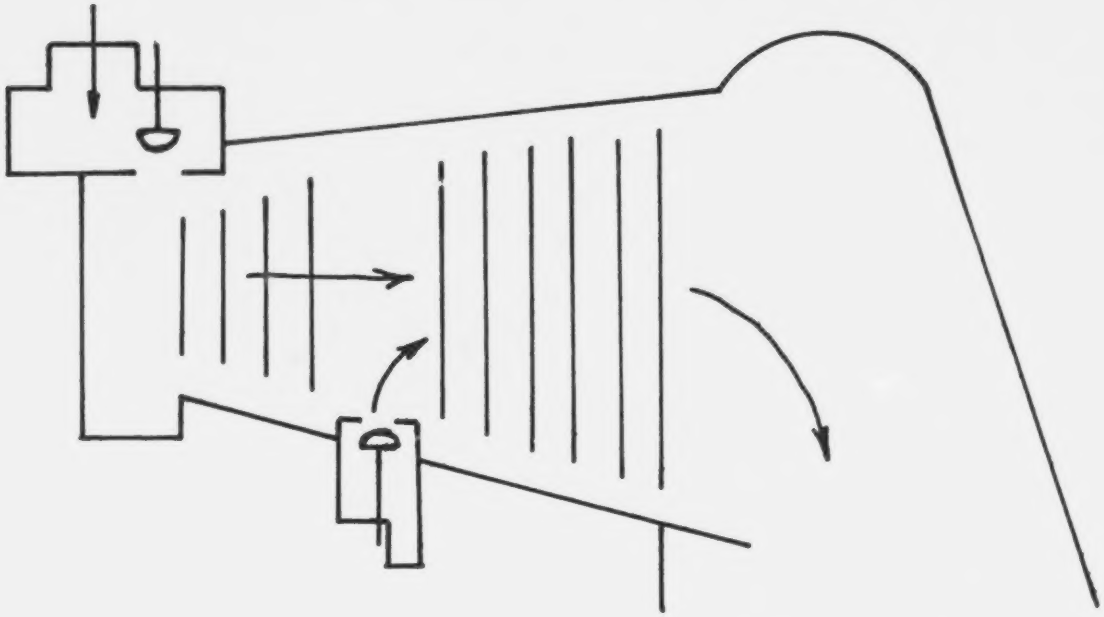
NON-CONDENSING

12-A-1-4



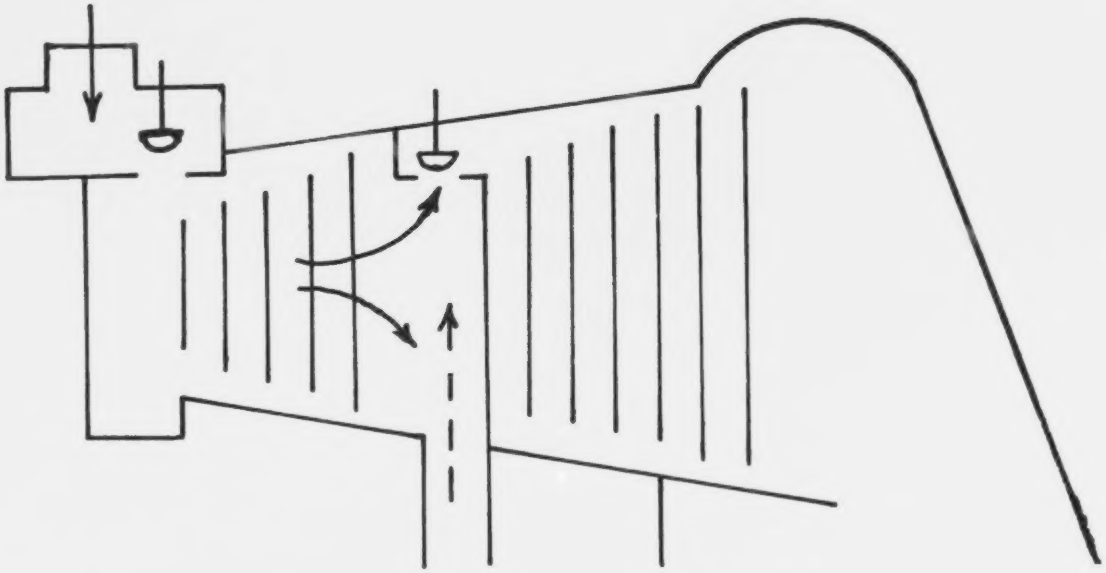
EXTRACTION TURBINE-
RUNNING CONDENSING

12-A-1-5



MIXED PRESSURE TURBINE-
RUNNING CONDENSING

12-A-1-6



MIXED-PRESSURE TURBINE
EXTRACTION-CONDENSING TYPE

12-A-1-7

Objectives: Be able to explain the theory of operation of an impulse turbine.

Be able to describe what happens to the pressure and to the velocity of the steam in a three-stage, velocity-compounded impulse turbine.

Information: The impulse turbine rotates because of a force acting in a forward direction on a blade or bucket mounted on a wheel. To produce the force, steam is expanded through a nozzle and acquires velocity before striking the blade. There may be many sets of blades in a given turbine, and they in turn can be divided into stages. There is a nozzle or nozzles fitted before each stage, in which the steam expands.

Let us now follow the path of the steam in the pressure/velocity diagram of a three-stage impulse steam turbine. See sketches 12–B–1–1, and 12–B–1–2. The steam enters the high-pressure nozzle and drops slightly in pressure as it passes through, but the steam velocity increases. The steam strikes the moving blades, imparting energy to the blades but losing velocity in the process. There is no pressure-drop going through the moving blades. The steam then enters the stationary blading and changes direction without loss of pressure or velocity. Once again the steam strikes a set of moving blades, with the corresponding drop in velocity but not in pressure.

As you may have noted, the velocity has dropped to the initial value. To increase it we must pass the steam through a nozzle, which will be the second stage. The velocity/pressure relationship is then repeated through the second and third stages. The pressure diagram shows a drop in pressure through the second- and third-stage nozzles before exhausting after the third stage.

We should remember the following facts about impulse steam turbines:

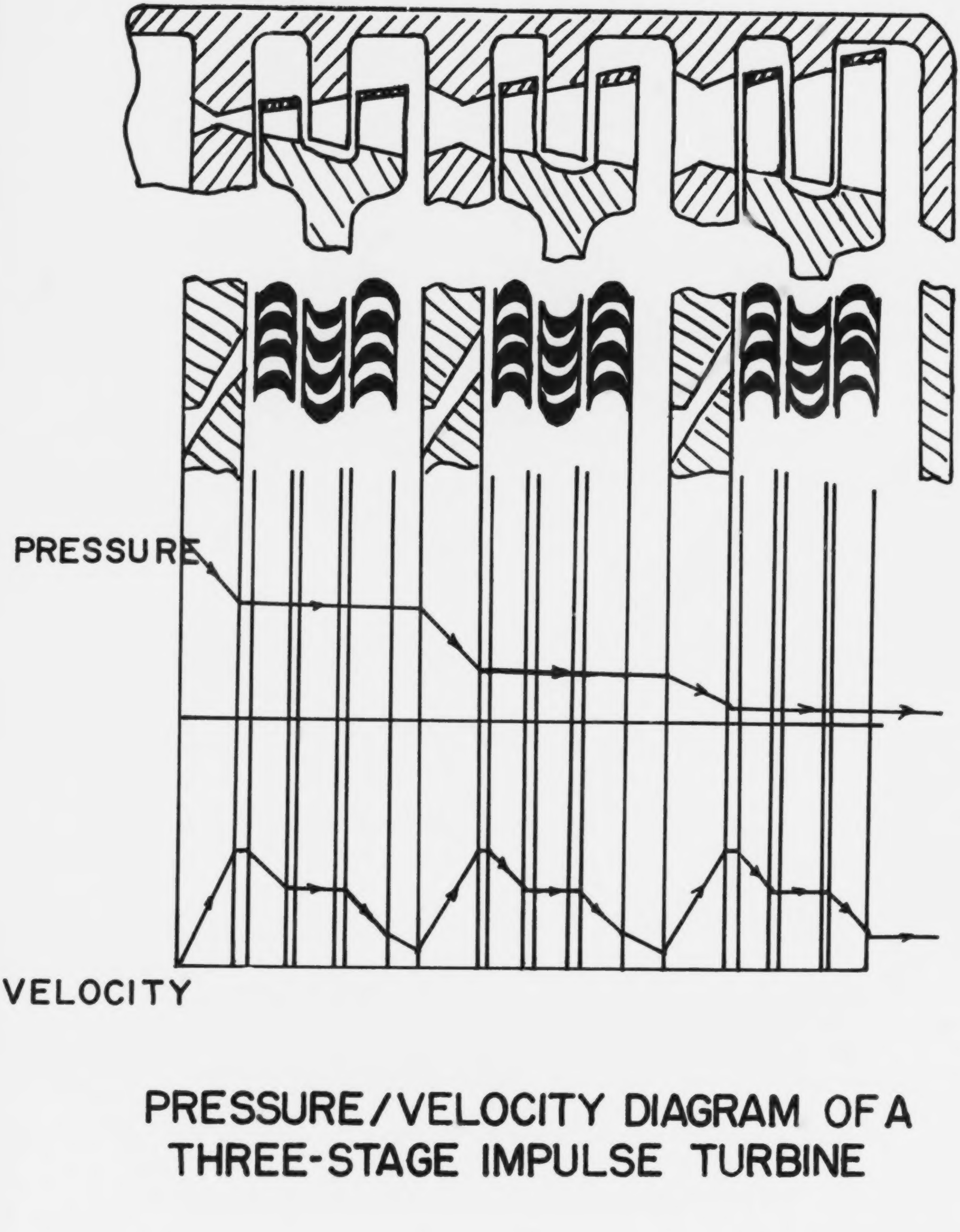
1. Force strikes a blade in a forward direction.
2. The steam's pressure drops and its velocity increases when passing through a nozzle.
3. The steam's velocity drops and its pressure remains the same through the moving blading.
4. The steam's velocity and pressure do not change as it goes through the stationary blades.
5. Some heat energy is given up to the moving blades, with a subsequent loss of velocity.

References: *Steam Plant Operation*
Elementary Steam Power Engineering

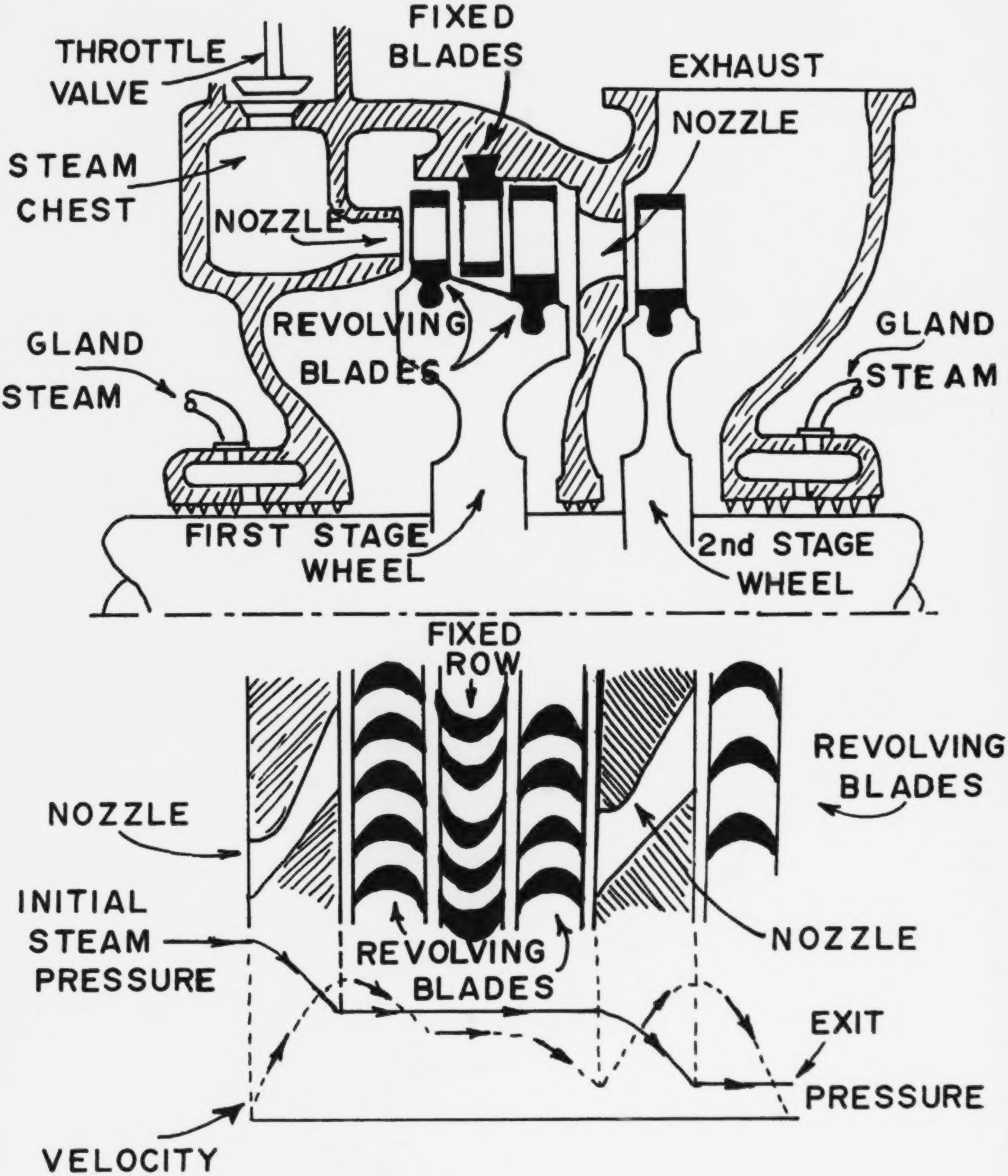
Procedure: After studying the information above and the listed references, answer the following questions.

Assignment:

1. What is the principle of operation of an impulse steam turbine?
2. Describe the pressure diagram of a three-stage, velocity-compounded impulse turbine.
3. Describe the velocity diagram of a three-stage, velocity-compounded impulse turbine.
4. Compare the pressure and velocity diagrams.


PRESSURE
VELOCITY

PRESSURE/VELOCITY DIAGRAM OF A THREE-STAGE IMPULSE TURBINE


FIXED BLADES
THROTTLE VALVE
EXHAUST
NOZZLE
STEAM CHEST
NOZZLE
REVOLVING BLADES
GLAND STEAM
GLAND STEAM
FIRST STAGE WHEEL
2nd STAGE WHEEL
FIXED ROW
REVOLVING BLADES
NOZZLE
INITIAL STEAM PRESSURE
REVOLVING BLADES
NOZZLE
EXIT PRESSURE
VELOCITY

TWO-STAGE IMPULSE TURBINE

Objectives: Be able to list the essential parts of an impulse turbine and explain the purpose of each part.

Be able to name and explain the purpose of the bearings, the packing, and the clearances.

Information: The essential parts of an impulse steam turbine are:

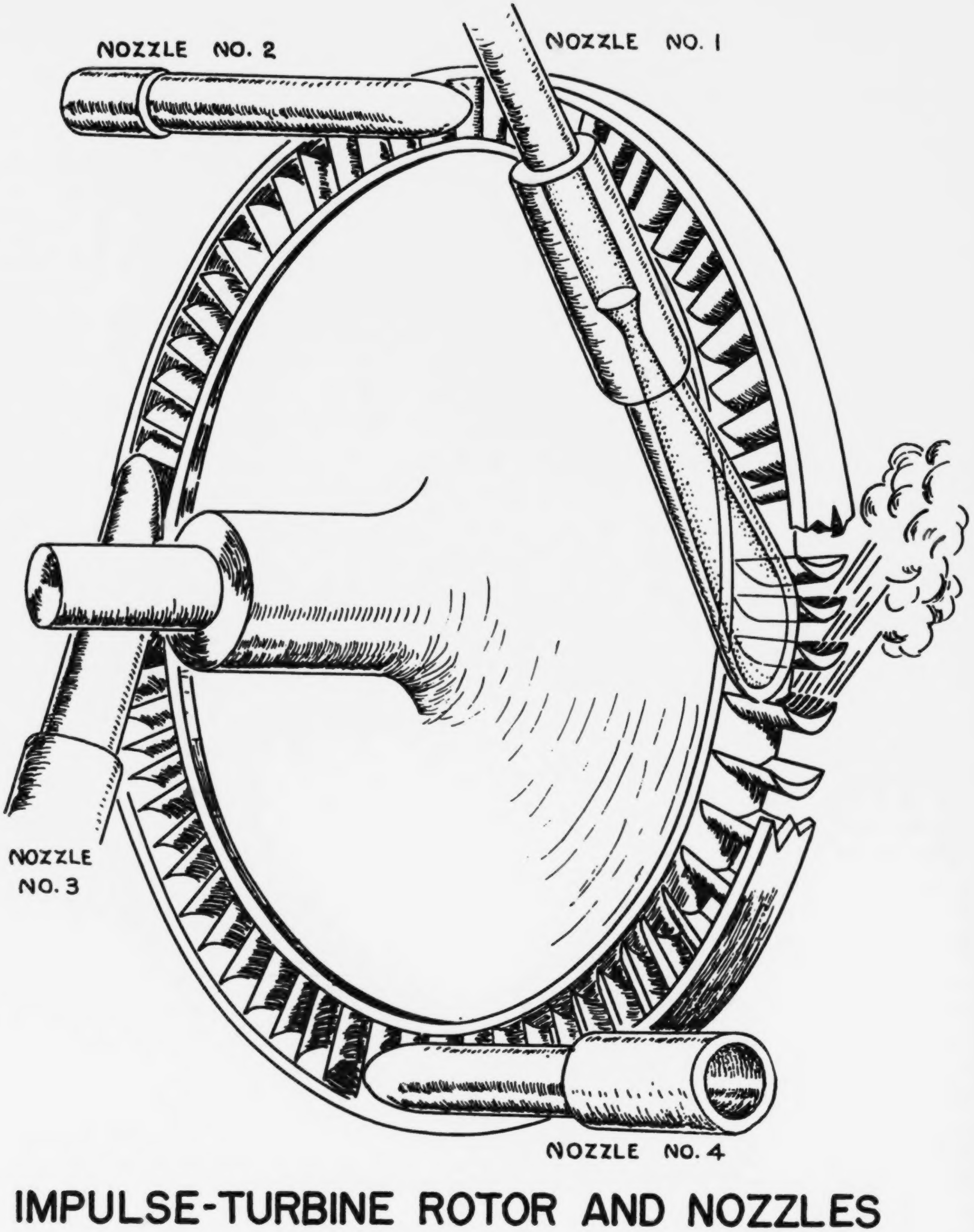
1. **Shaft** – upon which are mounted wheels. On the outer edges of the wheels, **blades** are attached.

2. **Nozzles** – fitted before each pressure stage. Nozzles are fitted on stationary **diaphragms** separating the wheels. The purpose of diaphragms is to seal each stage against steam leakage. At the points where the diaphragms join the rotating shaft, a **steam seal** must be fitted to prevent the higher pressure of one stage from leaking through to the next stage. Usually some form of labyrinth packing is used (see sketch 12–B–1–2).

3. **Throttle valve** – to govern amount of steam admitted to turbine. Controlled by hand, with a tripping device for low-lubrication pressure built in. In addition to manual control on the throttle valve, a **governor** is usually found. The governor is an automatic speed-regulating device to prevent a machine's "running away" if the load suddenly drops.

   Two basic types of governors are built:
   a) A cut-off or emergency tripping device designed to cut off all the steam until reset by hand.
   b) A speed-control governor that does not shut off steam entirely but positions the governor-controlled admission valves to maintain a constant speed.

4. **Shaft glands** – Where the turbine shaft emerges from the turbine casing, there exists a source of steam leakage unless sealed by glands.
   a) High-pressure end prevents steam leakage to atmosphere.
   b) Low-pressure end prevents air from entering turbine.
   c) Most widely used form of seal is labyrinth packing.


NOZZLE NO. 2
NOZZLE NO. 1
NOZZLE NO. 3
NOZZLE NO. 4

IMPULSE-TURBINE ROTOR AND NOZZLES

5. **Rotor** — The shaft and its rotating wheels, and the blades mounted on the outer rims of the wheels.

Bearings

The rotor, although rotating, must remain in a fixed position within the casing. This is accomplished by means of bearings, both radial and thrust.

Radial bearings: fix the vertical position of the rotor.

Thrust bearings: fix the fore and aft position of the rotor.

NOTE: If either radial or thrust bearing clearance becomes greater than the turbine clearances, rubbing will occur. Physical contact between the rotor and the casing will result in overheating, which will cause distortion and subsequent damage.

Radial bearings (main bearings):
Function: To prevent or maintain the rotor in proper alinement with the casing and to take the load developed.

Construction: Usually two cast-iron shells lined with babbitt metal and provided with spherical self-alining pads. All bearings are bored and scraped to the shaft before use. Clearance allowed is one-thousandth of an inch per inch diameter of journal. The journal is that part of a shaft revolving within the bearing. Thus a 10" shaft would rotate in a bearing whose inner diameter is 10.010 inches.

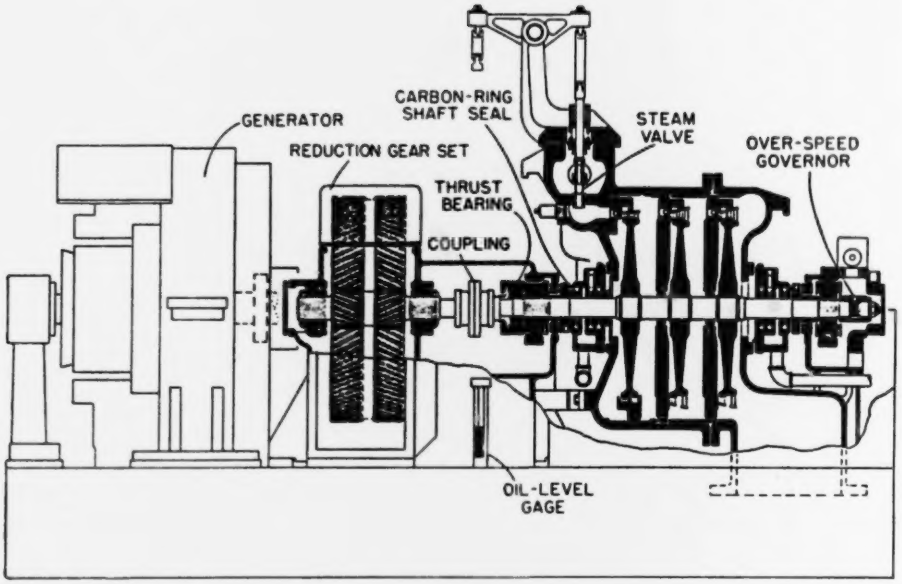
Thrust bearings: Usual form of thrust bearing is the movable-shoe type known as the kingsbury thrust bearing.

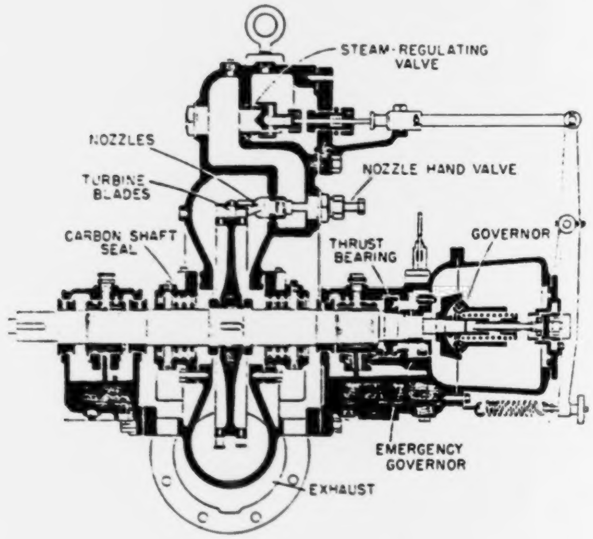
Function — two-fold:

1. Compensate for variable axial thrust generated by the turbine.
2. Fix the axial position of the rotor.

Labyrinth packing

Principle of operation: As steam leaks through the very narrow space between packing strips and the shaft, its pressure falls and its velocity increases (The leak forms a kind of nozzle). On entering the pocket or space between the strips, however, the velocity acquired by the expansion is largely lost due to the eddy motion. As a result of this, the velocity with which the steam begins the next throttling is very small. Therefore the more packing strips there are, the smaller the leakage, the smaller the pressure drop, and the smaller the velocity increase at each throttling.

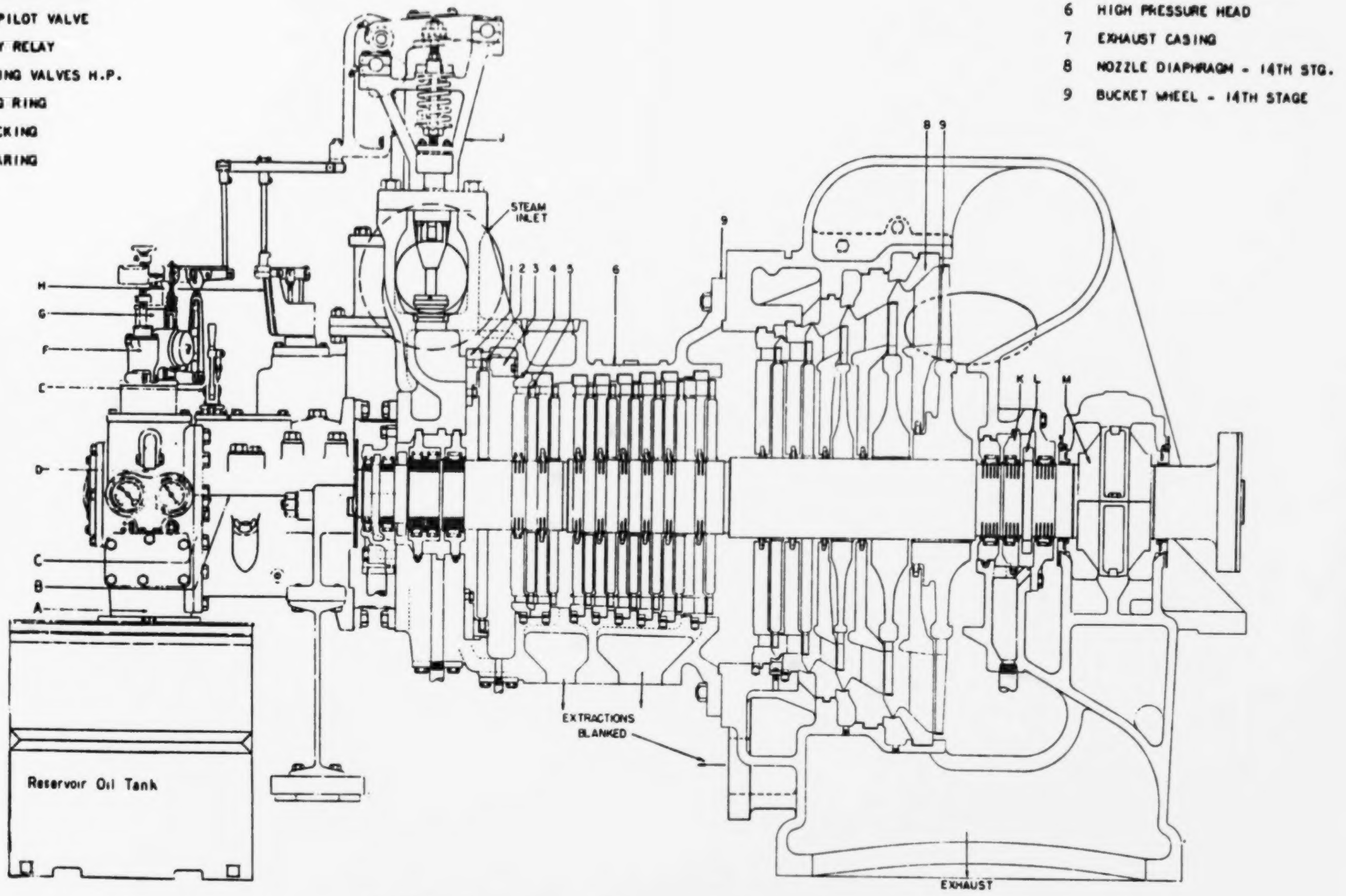

CARBON-RING SHAFT SEAL
STEAM VALVE
GENERATOR
REDUCTION GEAR SET
OVER-SPEED GOVERNOR
THRUST BEARING
COUPLING
OIL-LEVEL GAGE


STEAM-REGULATING VALVE
NOZZLES
NOZZLE HAND VALVE
TURBINE BLADES
CARBON SHAFT SEAL
THRUST BEARING
GOVERNOR
EMERGENCY GOVERNOR
EXHAUST

IMPULSE TURBINES

A	OIL PUMP AND GOVERNOR DRIVE
B	THRUST BEARING
C	EMERGENCY GOVERNOR
D	SPEED GOVERNOR
E	EMERGENCY TRIPPING DEVICE
F	SYNCHRONIZING DEVICE
G	PRIMARY PILOT VALVE
H	SECONDARY RELAY
J	CONTROLLING VALVES H.P.
K	BALANCING RING
L	SHAFT PACKING
M	SHAFT BEARING

1	NOZZLE PLATE - 1ST STAGE
2	BUCKET WHEEL - 1ST STAGE
3	STEAM DISTRIBUTOR
4	NOZZLE DIAPHRAGM - 2ND STG.
5	BUCKET WHEEL - 2ND STAGE
6	HIGH PRESSURE HEAD
7	EXHAUST CASING
8	NOZZLE DIAPHRAGM - 14TH STG.
9	BUCKET WHEEL - 14TH STAGE


J
STEAM INLET
H
G
F
C
D
C
B
A
1 2 3 4 5
6
9
8 9
K L M
EXTRACTIONS BLANKED
Reservoir Oil Tank
EXHAUST

IMPULSE TURBINE

Bearing lubrication

Usually force-feed. Deflectors must be fitted to prevent leaking gland steam from contaminating the oil. Wear of the main (radial) bearing will cause the shaft and rotor to drop. Care must be taken to determine at all times the condition of the bearings. This is accomplished by two methods.

1. Bridge gage
2. Bearing micrometer gage

Clearances: Turbine clearances are comparatively small.

Radial clearances: Clearances between top of moving blades and casing may vary from 0.180 to 0.250 inches.

Axial clearance: Distance between the nozzle exits and the leading edge of the blade may be between 0.100 and 0.200 inches.

Diaphragm gland clearances: These clearances are really the smallest and may run as low as .002 of an inch.

These clearances are cold clearances. When the turbine is warmed up and running, these clearances diminish considerably.

References: *Steam Plant Operation*
Elementary Steam Plant Engineering

Procedure: After studying the information above and the listed references, answer the following questions.

Assignment:

1. List the essential parts that make up an impulse steam turbine.
2. Describe the purpose of each part in detail.
3. What is the principle of operation of an impulse turbine?
4. Where does the expansion of steam take place in an impulse turbine?
5. What happens to the steam when it is allowed to expand?
6. What purpose do gland seals serve?
7. What are radial clearances? What radial clearances are permitted on an impulse turbine?

8. What is axial clearance? How much is needed on an impulse turbine?

9. What are diaphragm gland clearances and how much do they have to be?

10. How is the rotor kept in a fixed position in relation to the casing?

11. What type of thrust bearing is used on a turbine?

12. Describe how labyrinth packing prevents leakage on a shaft. (Use a sketch to illustrate.)

Objectives: Be able to explain the theory of operation of a reaction steam turbine.

Be able to describe the pressure/velocity diagram of a two-stage reaction steam turbine.

Information: The basic principle of operation of a reaction turbine is illustrated by an ordinary lawn sprinkler. Water under pressure is introduced at the center of sprinkler, and from there it branches to the arms. On leaving the open end of these arms, the pressure energy is converted to velocity or kinetic energy. As the water leaves, the arms move *backward* in reaction to the *forward* force of the water.

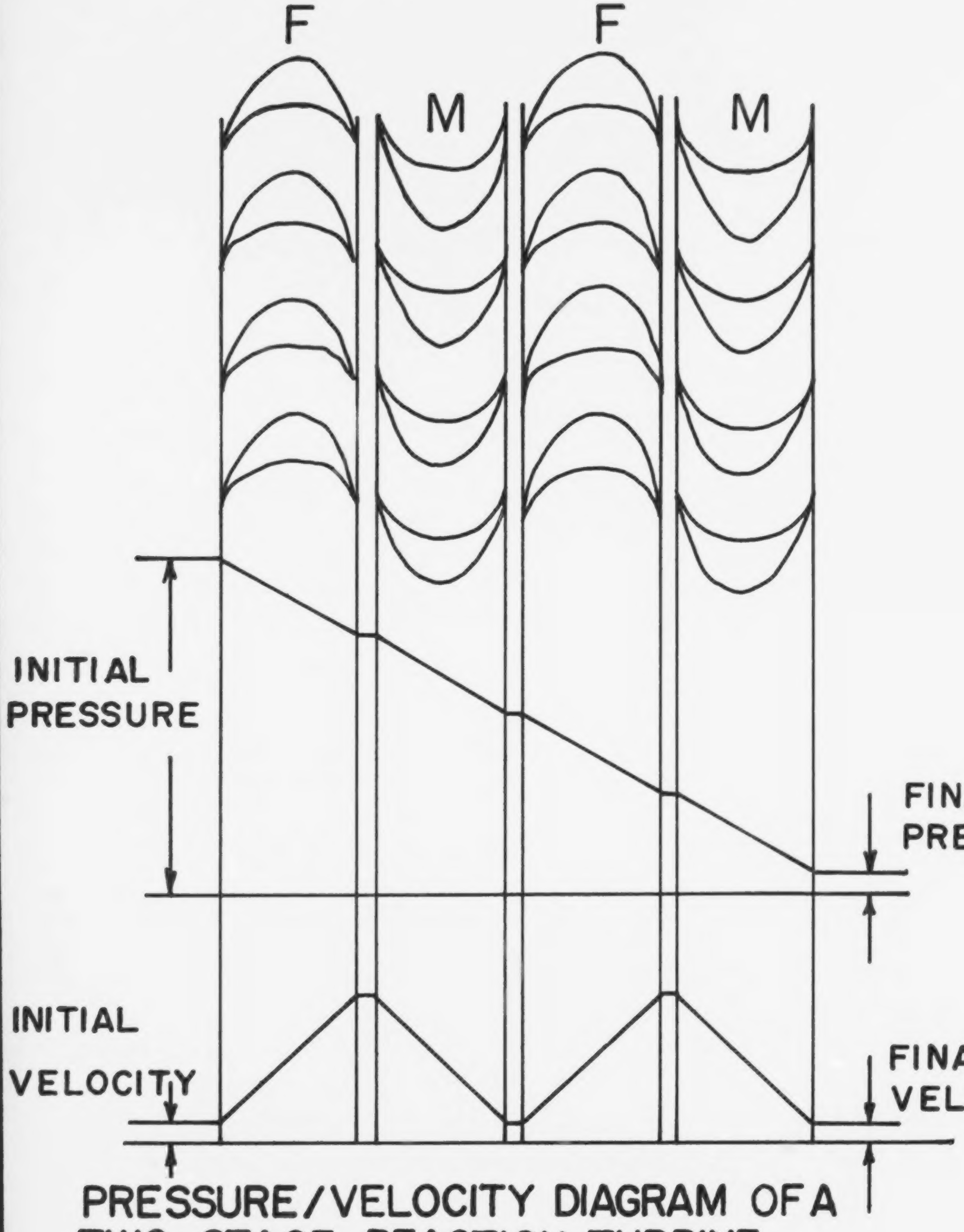
Newton accounts for this motion in one of his laws of motion:

> *For every action there is an equal and opposite reaction.*

The reaction-type turbine uses this principle for part of its action. Instead of nozzles, the reaction turbine uses fixed blades for its initial stage. Fixed blades are so designed that each pair acts as a single nozzle. Steam expands between each pair of blades. The expanding steam acquires velocity in the same manner as in the impulse nozzle. This steam, with its high velocity, now enters the blades of the moving element, imparting a direct impulse to it in exactly the same manner as in the impulse turbine.

But, instead of exhausting through the remainder of the blade passage without further expansion, as in the impulse turbine, the steam is directed into nozzle-shaped blade passages for the remainder of its travel. Within these nozzle-shaped passages, the steam expands and by so doing acquires additional velocity. In leaving the turbine blades at a high velocity, a *backward kick* is given the blades; thus the term "reaction."

Let us follow the path of the steam through the pressure/velocity diagram of a two-stage reaction turbine. See Sketch 12–C–1–1. The steam at its initial pressure enters the fixed blading and increases in velocity while losing pressure. The steam strikes the moving blading, giving up energy and losing velocity. As the steam leaves, it gives a reactive force to the moving blades, and a loss of pressure occurs. The second stage begins as the steam enters the next row of fixed blades. Again the velocity increases and some pressure is lost in the fixed blades. Then it loses velocity and pressure through the moving blading. Because of the difference in pressure between the entrance and exit sides of both stationary and moving blades, the


F
M
F
M
INITIAL PRESSURE
FINAL PRESSURE
INITIAL VELOCITY
FINAL VELOCITY

PRESSURE/VELOCITY DIAGRAM OF A TWO-STAGE REACTION TURBINE

12-C-1-1

reaction turbine is a full-admission turbine. Admission of steam takes place completely around the rotor. In the impulse turbine, only those nozzles need to be opened to produce the flow required.

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Procedure: After studying the above information and the listed references, answer the following questions.

Assignment:

1. What is the principle of operation of a reaction steam turbine?
2. Describe a pressure/velocity diagram of a reaction steam turbine.
3. Compare the pressure/velocity diagrams of the impulse and reaction turbines.
4. Does the reaction turbine work only by reaction force? Explain your answer.

Objectives: Be able to list the essential parts that make up a reaction turbine.

Be able to explain the purpose of each part of a reaction turbine.

Be able to describe the construction features that minimize leakage in a reaction turbine.

Information: The essential parts of a reaction steam turbine are:

1. **Stationary blading** that is fastened to the housing and acts as nozzles when steam enters.
2. **Moving blades** that are mounted on **drums** or **cylinders** to form the rotor. Steam gives up energy to the blading as it passes through.
3. The **throttle** and **governor** system are the same as in an impulse turbine.
4. **Shaft glands, bearings, both radial and thrust, lubrication,** and **labyrinth packing** are used for the same purposes in a reaction as in an impulse turbine.

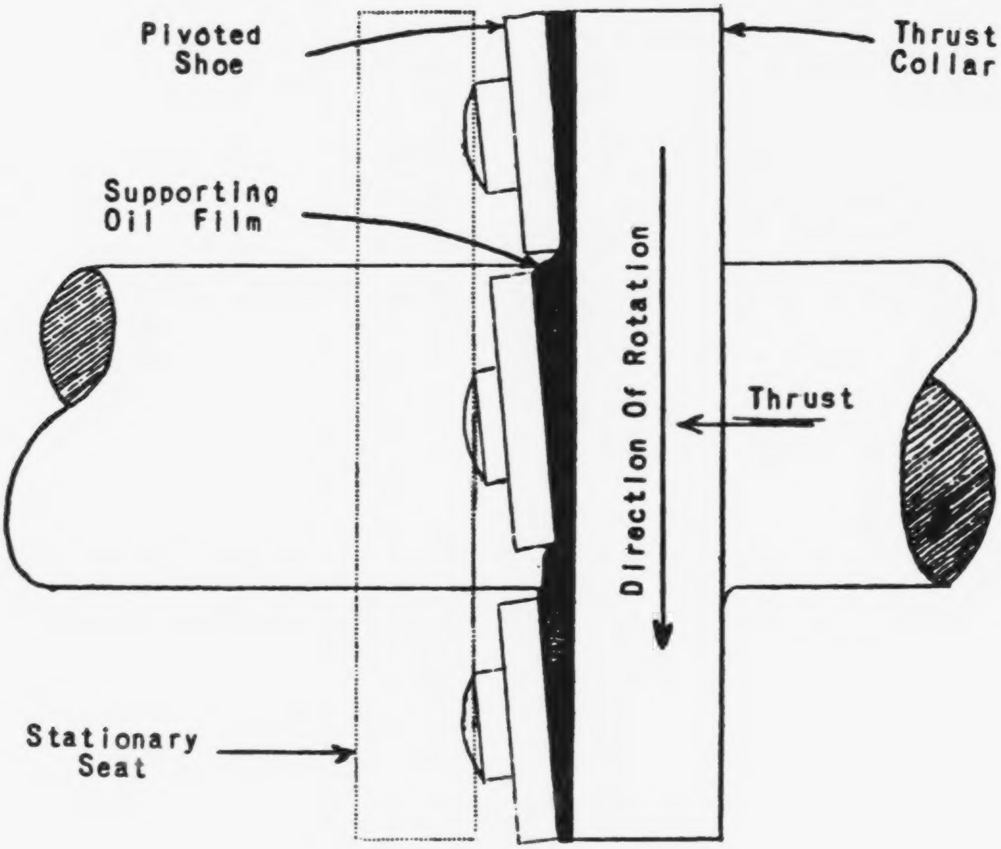
Axial thrust

The wheel of the *impulse* turbine revolves in chambers with equal pressure on each side. Therefore there is no end-thrust due to unbalanced pressures, provided that the shaft is substantially the same diameter at the high-pressure and the exhaust ends.

End of axial thrust must be carefully considered in reaction turbines, however. First, there is a cumulative pressure due to the drop in pressure across each row of blades. Second, there is also an axial thrust due to the pressure on the end of each drum when the diameter changes. (See sketch 12–C–2–1.)

Balance Piston

Modern turbines generally contain but one balance piston, designed to balance all thrust at full load on the machine. Any inequalities of thrust at other loads are taken care of by the thrust bearing itself. The balance piston is usually called the dummy piston. As but one end of the dummy piston should be exposed to the high pressure, some anti-leakage packing must be provided. A dummy cylinder is placed around the dummy piston. Between the two is placed dummy packing, which is labyrinth packing.


Pivoted Shoe
Thrust Collar
Supporting Oil Film
Direction Of Rotation
Thrust
Stationary Seat

A sketch showing the principle upon which the Kingsbury thrust bearing operates is drawn above. There is usually one collar on the shaft which bears against pivoted shoes. When the shaft is rotated, the shoes pivot so as to allow the film of oil between the bearing surfaces to take its required shape- that of a wedge.

Pressure on each side of every row of blades is different. This pressure difference is absolutely necessary, in order that steam may pick up velocity in each set of blades. This pressure difference causes difficulty, since leakage enters the picture. The steam tends to leak around the tops of the moving blades and under the bottoms of the fixed blades.

Two solutions to the problem of minimizing this leakage:

1. Reduce the clearances.
2. Allow only a small pressure difference to exist across each row of blades.

Both solutions are used.

Because certain characteristics of the reaction principle differ from the impulse principle, the physical characteristics of the reaction turbine are somewhat distinct.

1. Close mechanical clearance between the tips of fixed blades and the shaft. Close mechanical clearance between the moving blades and the casing.
2. A relatively large number of elements, permitting a small pressure drop per row of blades.
3. Moving blades mounted on drums or cylinders instead of on diaphragms.
4. Full admission of steam all around the blades.
5. Large end thrust, due to difference in pressure between stages, must be balanced by:
    a) Balance pistons of various sizes
    b) Dummy piston, which is merely a single balance piston
    c) Double flow of steam

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Procedure: After studying the information and the listed references, complete the following assignment.

Assignment:

1. List the major parts that make up a reaction steam turbine.

2. Describe the purpose of each part, in detail.

3. What is the principle of operation of a reaction turbine?

4. What does the reaction turbine use for its initial stage?

5. How is leakage around fixed and moving blades prevented in a reaction turbine?

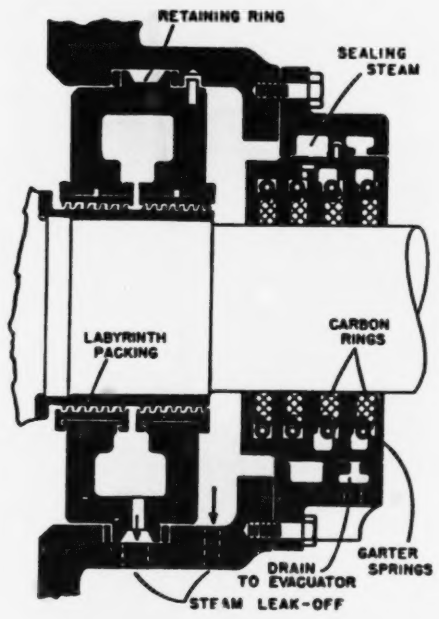
6. How does steam admission in a reaction turbine differ from that in an impulse turbine?

7. How is axial thrust taken care of in a reaction turbine?

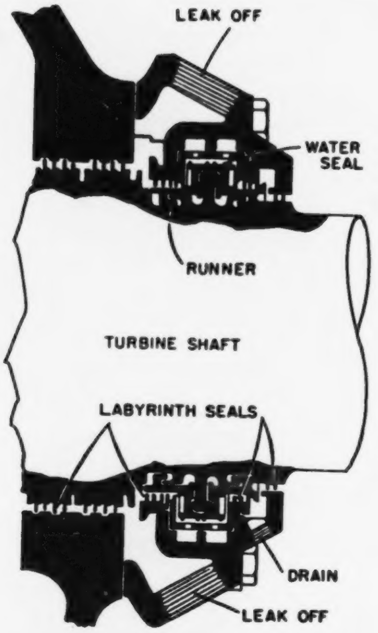
8. Which turbine, reaction or impulse, will have a greater thrust? Explain in detail.

9. Explain how a dummy or balance piston works.

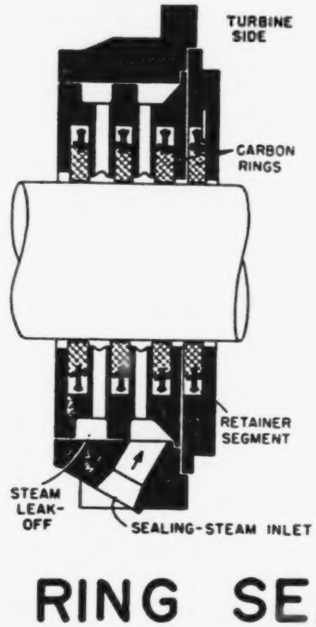
10. State the construction features of a reaction turbine that are designed to minimize leakage. Describe each.


RETAINING RING
SEALING STEAM
LABYRINTH PACKING
CARBON RINGS
GARTER SPRINGS
DRAIN TO EVACUATOR
STEAM LEAK-OFF

CARBON RING & LABYRINTH SEAL


LEAK OFF
WATER SEAL
RUNNER
TURBINE SHAFT
LABYRINTH SEALS
DRAIN
LEAK OFF

WATER AND LABYRINTH SEAL


TURBINE SIDE
CARBON RINGS
RETAINER SEGMENT
STEAM LEAK-OFF
SEALING-STEAM INLET

CARBON RING SEAL

Objective: Be able to describe the construction of an impulse-reaction turbine and explain its advantages.

Information: Steam turbines are made that combine both impulse and reaction blading. Usually there are several stages of impulse blading in the high-pressure end of the turbine, where it can take advantage of large pressure drops through the nozzle. The reaction blading, in the low-pressure end, has small pressure drops across each row of blades.

Reaction turbines, as you may recall, have small pressure drops per stage, which means small amounts of steam expansion, with the accompanying low output of work per stage. Therefore, in order to obtain the full range of pressure-drop throughout the turbine, many stages must be used. The reaction turbine is therefore a larger machine than an impulse turbine of the same power output.

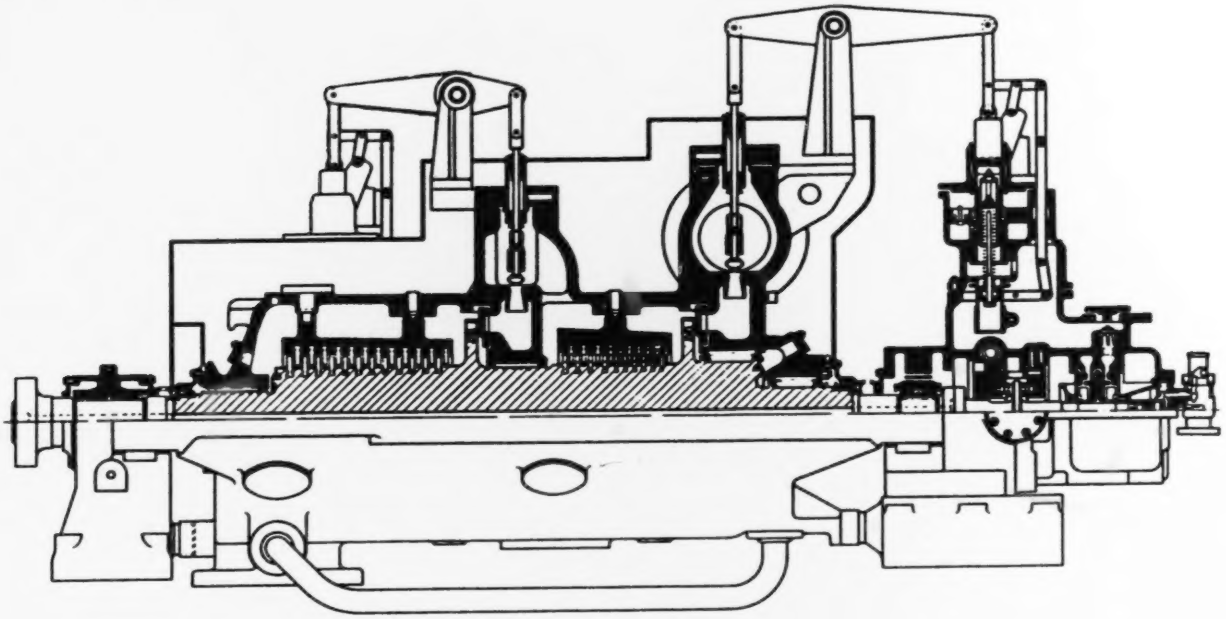
The impulse turbine is primarily a high-speed machine that utilizes large pressure drops. It is smaller with less weight and lower cost than a reaction turbine of the same capacity. The reaction turbine is basically a low-pressure turbine because of losses around the blading at higher pressures. When both are combined into an impulse-reaction turbine, we have the best of both machines. Usually the turbine is run on a high vacuum for even greater efficiency.

In these combination turbines, sometimes regular nozzles are used. In others, the stationary reaction blades act as a series of nozzles directing the steam against the impulse blades.

The same parts exist in an impulse-reaction turbine as are in the separate turbines. The governor controls the steam admission to the first stage, and the overspeed and low-oil-pressure trip will still stop the steam to the turbines if the need arises.

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Procedure: After studying the information and the listed references, answer the following questions.



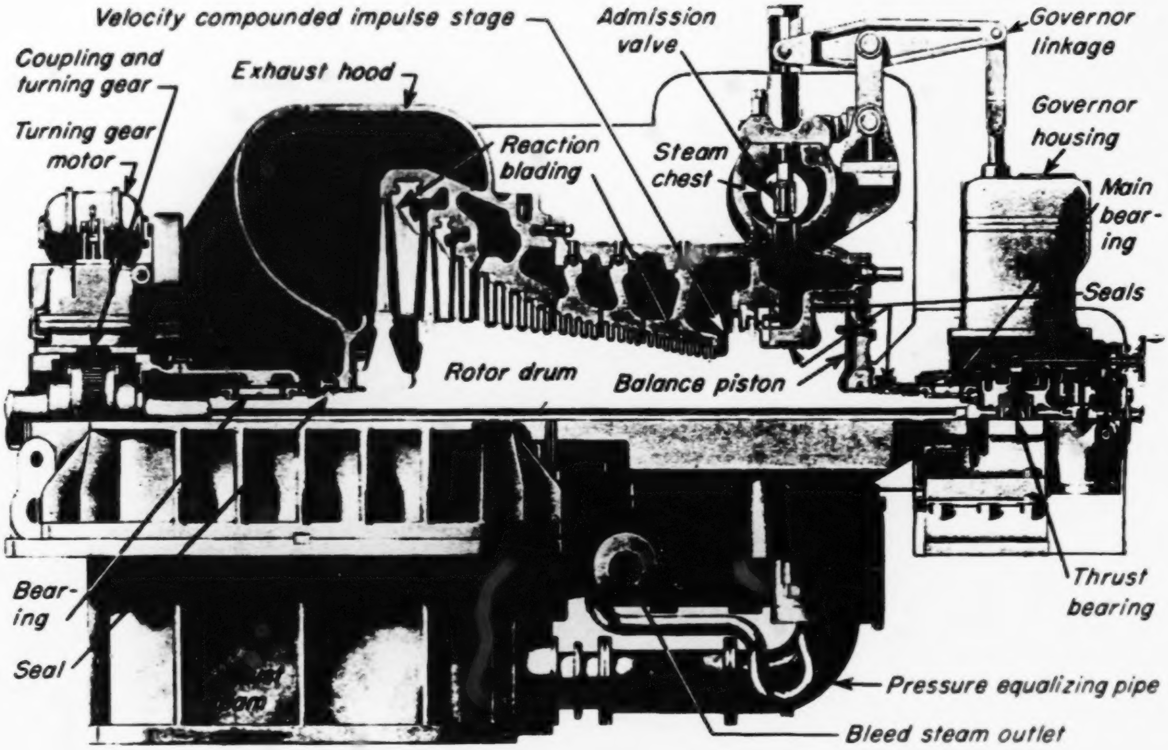
IMPULSE - REACTION

SINGLE-EXTRACTION NONCONDENSING

217 12-D-1-1

Assignment:

1. What are the advantages of combining impulse and reaction blading in one turbine?
2. Where is the impulse blading usually found in impulse-reaction turbines? Why?
3. Where is the reaction blading usually found in an impulse-reaction turbine? Why?
4. What type of steam leakage occurs in impulse-reaction turbines?
5. What controls the speed of this type of turbine, and what safety trips does it have?
6. What advantage is there to using stationary reaction blading in conjunction with impulse blading?


Velocity compounded impulse stage
Admission valve
Governor linkage
Coupling and turning gear
Exhaust hood
Governor housing
Turning gear motor
Reaction blading
Steam chest
Main bearing
Seals
Rotor drum
Balance piston
Bearing
Thrust bearing
Seal
Pressure equalizing pipe
Bleed steam outlet

WESTINGHOUSE
IMPULSE-REACTION TURBINE

Objectives: Be able to state the reasons for using a noncondensing turbine.

Be able to state the reasons for using a condensing turbine.

Information: Steam turbines that exhaust at atmospheric pressure or above are classified as noncondensing turbines. They are normally used in steam plants that require large amounts of low-pressure process or heating steam. An example would be a paper mill that heats a considerable amount of water. If the exhaust steam is not used but just allowed to go to waste in the atmosphere, the turbine would have a very low thermal efficiency. It would waste a considerable amount of energy. Small noncondensing turbines are sometimes used to drive boiler feed-water pumps, and the steam exhaust from the turbine is used to heat the feed-water in the open heater. Whenever a noncondensing turbine is run in a plant, it is essential for efficient operation to be able to use all, or a large part, of the exhaust steam.

Condensing steam turbines are normally used on medium to large units. They operate with an exhaust pressure of 26" Hg to 29" Hg vacuum. This allows the steam to expand to a greater volume and give up more heat, therefore doing more work. We can say then that an increase in the vacuum on the exhaust of a steam turbine will increase the efficiency of the unit. The higher the vacuum, the greater the efficiency will be. Another gain when condensing is that you are able to reclaim your condensate for reuse. The condensate is returned with some heat still in it to the open feed-water heater. We may sum up as follows:

1. Noncondensing
   a) Has high efficiency if all of the exhaust steam is used.
   b) Has poor efficiency if exhaust is allowed to go to the atmosphere.
   c) There is no condensate return.

2. Condensing
   a) Efficiency increases with increase in vacuum.
   b) Condensate can be reclaimed.
   c) Heat in condensate can be reclaimed.

Plant conditions will decide the type best suited for any given use. A plant is normally designed to get the maximum plant efficiency and may use both condensing and noncondensing turbines.

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Procedure: After studying the information and the listed references, answer the following questions.

Assignment:

1. Describe a noncondensing steam turbine.
2. Is the efficiency of a noncondensing turbine constant? Explain.
3. Describe a condensing steam turbine.
4. How is the efficiency of a condensing turbine increased?
5. Why is it important to save the condensate?
6. Explain how you could possibly use a condensing and noncondensing turbine in the same plant.
7. What are the advantages and disadvantages to the plant of condensing and noncondensing turbines?

Number of Steam Expansions in a Turbine — Assignment 12–E–1–M1

Objective: Be able to determine the number of steam expansions in a turbine.

Information: As steam passes through a turbine, its volume increases. This increase in volume is largely determined by the difference in pressure between admission and exhaust steam. The ratio between its exhaust volume and its original volume is called the number of expansions. The greater the number of expansions, the more energy is given up to the turbine to do useful work.

To find the number of expansions we can use the following formula:

$$\text{No. of Expansions} = \frac{\text{Specific volume of exhaust}}{\text{Specific volume of admission}}$$

$$\text{Exp} = \frac{SV_E}{SV_A}$$

Where
Exp. = Number of times steam changed volumes
SV_E = specific volume of exhaust steam in cubic feet per pound
SV_A = specific volume of admission steam in cubic feet per pound

NOTE: For our purposes we are assuming that the admission and exhaust steams are saturated, with a quality of 100%.

Example 1: How many times is steam expanded in going through a turbine from 120 p.s.i. to 28" vacuum?

From saturated-steam tables:

At 120 p.s.i. – 3.33 cubic feet/pound
At 28" vacuum – 333 cubic feet/pound

$$\text{Exp} = \frac{SV_E}{SV_A} = \frac{333}{3.33} = 100$$

Example 2: How many times will steam expand going through a turbine from 400 p.s.i.a. to 29" vacuum?

At 400 p.s.i.a. – 1.16 cubic feet/pound
At 29" vacuum – 633 cubic feet/pound

$$\text{Exp} = \frac{SV_E}{SV_A} = \frac{633}{1.16} = 546$$

Procedure: After studying the information and sample problems, do the following problems.

Assignment:

In the following problems, assume that the steam is 100% saturated.

1. How much will the steam change in volume in a 2500 kw turbo generator running with a steam pressure of 200 p.s.i. and exhausting at 28" vacuum?
2. How many times is steam expanded in going through a turbine from 150 p.s.i. to a 28" vacuum?
3. What is the specific volume of steam at the inlet of a turbine with a pressure of 250 p.s.i.? What is it at the exhaust, with a pressure of 28½" vacuum?
4. A turbine is operating at 350 p.s.i.a. and 28½" vacuum. How many times does steam expand going through the turbine?

Objective: Be able to explain the meaning of water rate and the conditions that affect it.

Information: The water rate of a steam turbine is the amount of steam or water used in pounds per unit of power output, under operating conditions. It is stated as pounds of water per horsepower-hour or per kilowatt-hour. This means that it has required a given amount of steam-flow to produce each horsepower-hour or kilowatt-hour. The admission and exhaust conditions of the steam can affect the water rate. The admission steam can be saturated or superheated, and the exhaust may have a high or low quality. Superheated admission steam and a low-quality exhaust steam will both lower the water rate.

Condensing also has the effect of lowering the water rate compared with a noncondensing unit of the same size. It is possible, if enough supporting data is available, to find the thermal efficiency of any steam turbine. This is not usually necessary, though, as you can take a water-rate reading regularly, and any change that occurs can be looked into. The average water rate for a noncondensing turbine is 24 pounds per kilowatt-hour and for a condensing unit 14 pounds per kilowatt-hour.

Refernces: *Steam Plant Operation*
Elementary Steam Power Engineering

Procedure: After having studied the information and the listed references, answer the following questions.

Assignment:

1. Define water rate.
2. What factors affect water rate?
3. Explain the use of water rate.
4. Is there a difference in water rate between condensing and noncondensing units? Explain.

Objective: Be able to determine the water rate of a steam turbine.

Information: Water rate is stated as the weight of steam used per unit of power output under actual operating conditions. The water rate of any turbine may be found by dividing the power output into the number of pounds of steam supplied to the turbine per hour.

$$\text{Water Rate} = \frac{\text{Pounds of steam/hour}}{\text{Kilowatts}} \quad \text{or} \quad \text{Water Rate} = \frac{\text{Pounds of steam/hour}}{\text{Horsepower}}$$

$$WR = \frac{W}{kw} \qquad WR = \frac{W}{hp}$$

Example 1: A turbine uses a total of 40,000 pounds of steam per hour while generating 2000 kw. Find the water rate.

$$WR = \frac{W}{kw} = \frac{40{,}000}{2000} = 20 \text{ pounds of steam/kw-hr}$$

Example 2: A turbine uses 25,000 pounds of steam per hour while putting out on a shaft 2000 brake horsepower. What is the water rate?

$$WR = \frac{W}{Bhp} = \frac{25{,}000}{2{,}000} = 12.5 \text{ pounds/Bhp-hr}$$

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Procedure: After studying the information and the listed references, complete the following assignment.

Assignment:

1. If a 10,000 kw generator uses 220,000 pounds of steam per hour, find its water rate.
2. If you had a 25,000 kw generator with a steam rate of 18 pounds per kw-hour, how much water would have to be pumped back into the boilers?
3. How many pounds of steam per hour will a 25,000 kw turbine use with a water rate of 16 pounds per kw-hour?
4. A 10,000 kw machine has a water rate of 30 pounds per kw-hour. Find the boiler horsepower needed for this machine.
5. A turbine is operating at 6000 kw with a water rate of 15 pounds per kw-hour. How much boiler horsepower is required with a feed-water temperature of 200° F?

Objectives: Be able to explain what is meant by the term "thermal efficiency."

Be able to explain how reclaiming condensate improves thermal efficiency.

Information: As far as efficiency is concerned, a steam turbine can be treated as either a mechanical device or a heat machine. In this unit we will look at it as a heat machine. We will compare the heat energy supplied against the heat energy it actually uses. This is known as thermal efficiency. The heat energy or enthalpy of steam supplied to a turbine minus the heat energy left in the steam at the exhaust shows you how much heat was used in the turbine. The ratio of the heat used to the heat supplied gives you the thermal efficiency.

$$\text{Thermal Efficiency} = \frac{\text{Heat used}}{\text{Heat supplied}}$$

In a **noncondensing** steam turbine, thermal efficiency would be found by this formula:

$$\text{Thermal Efficiency} = \frac{H_A - H_E}{H_A}$$

Where H_A = enthalpy of steam at throttle valve
H_E = enthalpy of steam at exhaust of turbine

For a **condensing** turbine with the condensate reclaimed,

$$\text{Thermal Efficiency} = \frac{H_A - H_E}{H_A - H_C}$$

Where H_C = enthalphy of the condensate

The enthalpy of the condensate is subtracted from the enthalpy of the admission steam because it is not used but is reclaimed. Therefore it cannot be charged to the turbine efficiency.

NOTE: We have for the purpose of simplification omitted heat losses such as radiation, etc.

References: *Steam Plant Operation*
Elementary Steam Power Engineering
Engineering Handbook

Procedure: After studying the above information and the listed references, answer the following questions.

Assignment:

1. Define thermal efficiency of a steam turbine.
2. What effect does condensing or not condensing have on thermal efficiency?
3. Set up and solve a thermal efficiency problem for a condensing and a noncondensing turbine. Assume all values, but make the Btu's per pound of steam at throttle the same for both turbines.
4. If the condensate in a condensing turbine were not reclaimed, write the formula for finding its thermal efficiency.

Objective: Be able to determine the thermal efficiency of a steam turbine.

Information: The thermal efficiency of a steam turbine may be found by using the following formula:

$$\text{Thermal Efficiency} = \frac{H_A - H_E}{H_A - H_C}$$

Where

H_A = enthalpy of the steam at throttle
H_E = enthalpy of the steam at exhaust
H_C = enthalpy of the condensate

Example 1: A 2500 kw turbine is operated with a steam pressure of 200 p.s.i.a. at 600°F. It exhausts into a condenser with a vacuum of 28½" Hg. What is the thermal efficiency of the turbine?

From the steam tables:

H_A = 1320 Btu per pound
H_E = 1100 Btu per pound
H_C = (95–32) Btu per pound

$$\text{Eff}_T = \frac{H_A - H_E}{H_A - H_C} = \frac{1320 - 1100}{1320 - (95-32)} = \frac{220}{1257} = .175 \text{ or } 17.5\%$$

Example 2: A 10,000 kw turbine is operated with a steam pressure of 450 p.s.i.a. at 900°F. It exhausts into a condenser with a vacuum of 28" Hg. What is the thermal efficiency of the turbine?

From the steam tables:

H_A = 1465 Btu per pound
H_E = 1105 Btu per pound
H_C = (101–32) Btu per pound

$$\text{EFF}_T = \frac{H_A - H_E}{H_A - H_C} = \frac{1465 - 1105}{1465 - (101-32)} = \frac{360}{1396} = .2578 = 25.8\%$$

As you may have noticed, the thermal efficiency increases as the pressure and temperature increase. The temperature limit is about 1050°F. for today's steels.

For our lesson we have assumed that the exhaust steam is 100% evaporated, whereas in actual practice there is 5 to 10 percent moisture in the exhaust steam. When this is taken into consideration, thermal efficiency is actually 5 to 6 percent higher than the figures indicate.

References: *Elementary Steam Power Engineering*
Steam Plant Operation

Procedure: After studying the information and listed references, answer the following questions.

Assignment:

1. What is the thermal efficiency of a steam turbine that operates with a throttle pressure of 350 p.s.i. at 600°F. and exhausts into a surface condenser at 29" Hg. vacuum?

2. What is the thermal efficiency of a condensing turbine under each of the following conditions (a, b, c, and d):

	(a)	(b)	(c)	(d)
Throttle pressure (p.s.i.a.)	150	200	250	300
Throttle temperature (°F.)	400	600	700	750
Exhaust pressure (p.s.i.)	.5	1	1.5	2

3. Make a comparison of the thermal efficiency of a condensing and noncondensing steam turbine. Assume all values. Make the Btu's per pound of steam at throttle the same for both turbines.

4. Assume that the condensate of a condensing turbine is not reclaimed. What does the formula given in this lesson reduce to?

Condensers – Types Assignment 12–F–1

Objectives: Be able to tell the function of a condenser.

Be able to explain the principles of a surface condenser and a barometric condenser, and give the advantages of each.

Information: A condenser is used to change the exhaust steam back to water by removing some of its heat. This causes a vacuum to be formed, thereby reducing the back pressure on an engine or turbine. There are two types of condensers.

A **surface condenser** could best be compared to a closed feed-water heater. The steam and cooling water do not mix.

Surface condensers may be classified as follows:

1. **Single- or double-pass.** – The cooling water circulates through tubes and the steam surrounds the tubes.
2. **Parallel-flow.** – Steam and cooling water flow in same direction.
3. **Counter-flow.** – Steam and water flow in opposite directions.

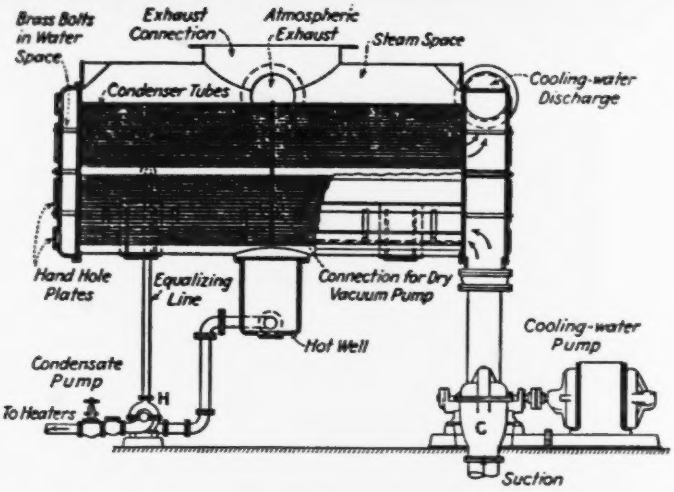
Advantages of using a surface condenser:
1. The condensate can be recovered for reuse.
2. The makeup water needed is held to a minimum.

A barometric **or jet condenser** is one in which the cooling water and steam come in direct contact with each other. (What type of feed-water heater would this remind you of?)

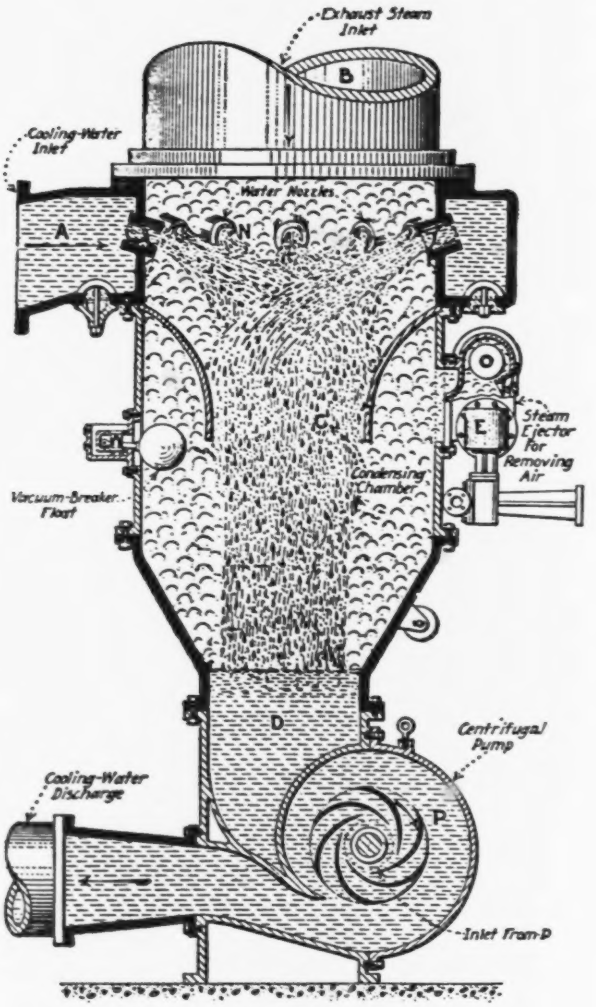
Advantages of using a barometric condenser:
1. It is all right to use fairly dirty condensing water.
2. The initial cost is less.
3. The operating cost is less.
4. It generally requires less maintenance.
5. It uses about 50% less cooling water than a surface condenser.

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Procedure: After studying the information and the listed references, answer the following questions and be prepared to discuss each.


Brass Bolts in Water Space
Exhaust Connection
Atmospheric Exhaust
Steam Space
Condenser Tubes
Cooling-water Discharge
Hand Hole Plates
Equalizing Line
Connection for Dry Vacuum Pump
Hot Well
Cooling-water Pump
Condensate Pump
H
To Heaters
C
Suction

SURFACE CONDENSER


Exhaust Steam Inlet
B
Cooling-Water Inlet
Water Nozzles
A
N
C
Steam Ejector for Removing Air
E
Vacuum-Breaker Float
Condensing Chamber
D
Centrifugal Pump
P
Cooling-Water Discharge
Inlet From P

JET CONDENSER

12 - F - 1 - 1

Assignment:

1. What is meant by a condensing engine?

2. What are advantages and disadvantages of condensing and noncondensing turbines?

3. a) What is a surface condenser?
   b) How are surface condensers classified?

4. What is meant by parallel-flow? counter-flow?

5. a) What are condenser tubes made of?
   b) How are they fastened in the tube sheet?

6. List at least four possible reasons for loss of vacuum.

7. How does a jet condenser differ from a surface condenser?

8. How are jet condensers classified?

9. Describe the types of jet condensers in detail.

10. About how many pounds of water are needed to condense one pound of steam?

11. When are jet-type condensers used rather than surface condensers?

Objective: Be able to describe various methods of supplying the condenser with cooling water.

Information: For years it was necessary to build generating stations alongside large bodies of water in order to supply the condensers with the large quantities of cooling water needed to condense the steam. At times as much as 50 pounds of water is needed to condense 1 pound of steam. Of course this figure will vary with changes in outside-air temperatures or cooling-water temperatures.

In time, with the increase in industrial demands and the growth in population, it became necessary to build plants where there was no free, available water. When there is no large supply of water, we must resort to a water recooling system. The system may be based on either a cooling pond or a cooling tower. Of the two, the cooling pond is the simpler, but not the more effective.

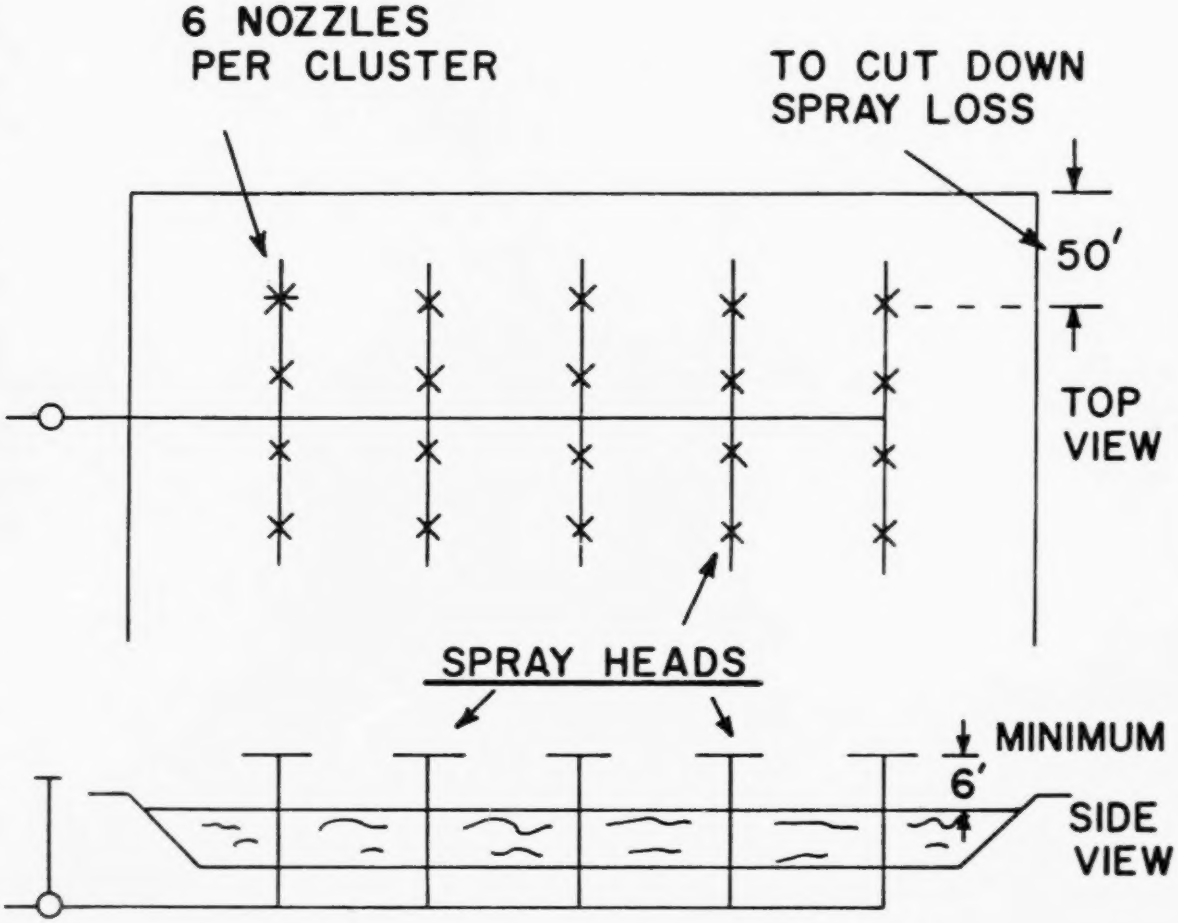
The **cooling pond** is cheaper if there is sufficient ground or roof area available. The cooling results, however, cannot compare with the results achieved with a tower.

The simplest method of cooling water would be by a single pipeline to a pond. The pond would have to be large enough to cool water to the temperature desired, merely by contact of the surface of the water with the atmosphere. This would require a pond too large in area to be practical. To overcome this, a spraying system is necessary.

The spray pond

To be effective, **the spray pond** must have the following features:

1. Low initial cost
2. Low operating cost
3. Large cooling range
4. Low maintenance
5. Good material and mechanical construction
6. Adjustments for fine or coarse spray
7. A minimum of piping in a small pond
8. Elimination of drifting of spray outside the pool
9. A means of cleaning the spraying mechanism without interfering with the cooling system's operation.


6 NOZZLES PER CLUSTER
TO CUT DOWN SPRAY LOSS
50′
TOP VIEW
SPRAY HEADS
MINIMUM
6′
SIDE VIEW

SPRAY POND

12-F-2-1

The spray nozzle should be able to break up the water into a spray suitable for weather conditions. It should also be able to atomize the water (make very fine droplets), thereby putting it into contact with as much air as possible.

The pressure of the cooling water may vary from 3 to 8 p.s.i., depending on the type of nozzle. The cooling effect will vary with weather conditions; it is generally from 20° to 40° F. The final temperature is often within 3 or 4 degrees of the air temperature. Under ideal conditions, the water temperature may actually get below the temperature of the air.

Water-cooling towers are classified as follows:

1. Natural draft – open or atmospheric-type
2. Natural draft – closed or flue-type
3. Forced draft
4. Induced draft
5. Combined forced and natural draft

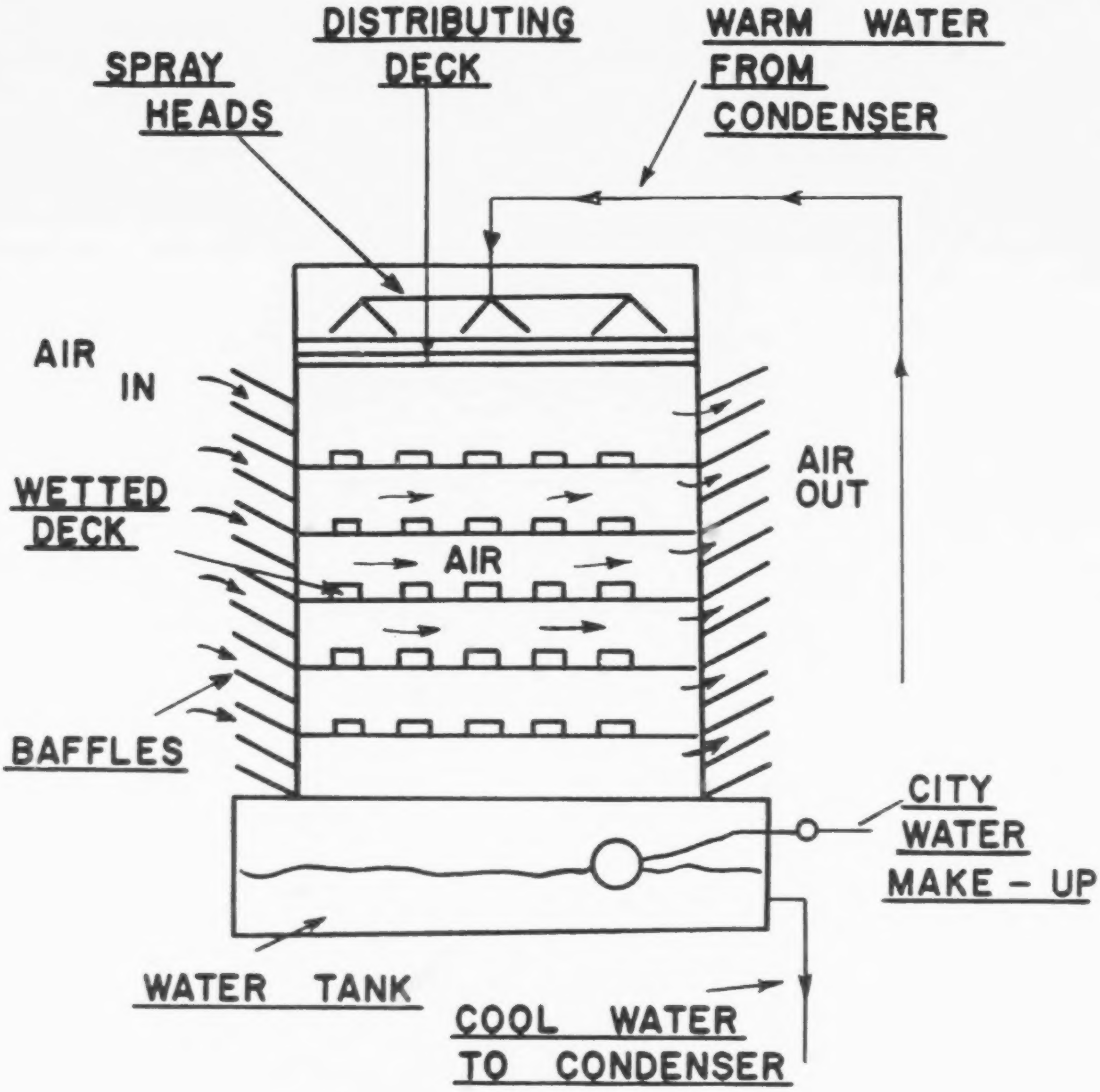
Generally the water is delivered to the top of the tower, then falls to a tank below the tower. The falling water is broken into a spray by some means not requiring pressure.

In operation, the water that is to be cooled is pumped to the system of troughs at the top of the tower and passes down through the weirs (individual channels that control the flow). It is cooled as it falls by gravity to a reservoir or tank below. This is a natural-draft tower. The natural-draft tower is gradually being replaced by the induced-draft type, which uses a fan to pull the air through. The induced-draft tower requires less ground area and less pumping head, suffers less draft loss, and has greater cooling efficiency during the summer months.

The principle upon which all cooling towers operate:

The water that is to be cooled gives up its heat to the rising column of air by evaporation, convection, and radiation. Evaporation absorbs from 75% to 85% of the heat given up.

The heat that must be extracted in the cooling tower is equal to the latent heat absorbed by the cooling water while condensing the steam in the condenser.


DISTRIBUTING DECK
SPRAY HEADS
WARM WATER FROM CONDENSER
AIR IN
WETTED DECK
AIR
AIR OUT
BAFFLES
CITY WATER MAKE - UP
WATER TANK
COOL WATER TO CONDENSER

NATURAL - DRAFT
COOLING TOWER

The cooling tower has to evaporate a quantity of water equaling from 75% to 85% of the weight of steam passing through the engine or turbine. The water being cooled may be lowered in temperature by 40° to 50°F.

The capacity of nozzles and cooling towers is measured in gallons of water per minute.

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Procedure: After reading the information and the listed references, answer the following questions and be prepared to discuss each in class.

Assignment:

1. Describe a cooling pond.
2. Describe a spray pond.
3. Why are cooling ponds and spray ponds used?
4. a) What is one main objection to a spray pond?
   b) How can it be corrected?
5. How does the cooling tower differ from a cooling pond?
6. How are water-cooling towers classified?
7. List the features required of a good spraying system.
8. Why is it necessary to use a spray nozzle?
9. How much pressure is required on spray-pond piping?
10. How much of a temperature-drop can you expect in using a spray pond?
11. Describe how a water-cooling tower works.
12. a) What methods of heat transfer are involved in cooling towers?
    b) Which absorbs the most heat?
13. How is the capacity of nozzles and cooling towers rated?

Objective: Be able to calculate the heat loss of a steam condenser.

Information: A large amount of the total heat supplied to a steam turbine is lost in the condenser. This is due to the high latent-heat value of water vapor. The engineer may wish to know just how much of this heat is being lost. It can be determined from the following formula:

$$\text{Percent Loss} = \frac{H_E - H_C}{H_A}$$

Where:

H_L = enthalpy of steam at exhaust
H_C = enthalpy of the condensate
H_A = enthalpy of steam at the throttle

Example 1: A 2500 kw turbine is operated with a steam pressure of 200 p.s.i.a. at 600°F. It exhausts into a condenser with a vacuum of 28½″ Hg. How much heat is lost to the circulating water in the condenser?

From the steam tables,

H_E = 1100 Btu per pound
H_C = (95–32) Btu per pound
H_A = 1320 Btu per pound

$$\text{Heat loss} = \frac{H_E - H_C}{H_A} = \frac{1100 - 63}{1320} = .7856 \text{ OR } 78.6\%$$

Example 2: A 10,000 kw turbine is operated with a steam pressure of 450 p.s.i.a. at 900°F. It exhausts into a condenser with a vacuum of 28″ Hg. What percent of the heat is lost to the condenser's circulating water?

H_E = 1105 Btu per pound
H_C = (101–32) Btu per pound
H_A = 1465 Btu per pound

$$\text{Heat loss} = \frac{H_E - H_C}{H_A} = \frac{1\ 105 - 69}{1465} = .707 \text{ OR } 70.7\%$$

Once again we have made the assumption that the steam at the exhaust end of the turbine is 100% evaporated. In practice there is 5 to 10 percent moisture content, and this decreases the loss of heat to the circulating water.

A method sometimes used to reduce this loss is to extract or bleed steam from the turbine at higher pressure stages for use as process steam. This reduces the amount of steam that has to be condensed in the condenser and therefore reduces heat loss. This will be covered in more detail in a later lesson.

Reference: *Steam Plant Operation*
Elementary Steam Power Engineering

Procedure: After studying the above information and listed references, answer the following.

Assignment:

Find the percentage of heat lost to the circulating water for the following turbines:

	Throttle Pressure	Throttle Temperature	Exhaust Pressure
a.	200 p.s.i.a.	600°F.	28" Vac.
b.	250 "	600°F.	28½" Vac.
c.	300 "	650°F.	29" Vac.
d.	450 "	700°F.	28" Vac.
e.	650 "	750°F.	29" Vac.

Objective: Be able to calculate the number of pounds of circulating water needed per pound of steam condensed, and also the total amount of water needed per hour.

Information: From the previous lesson you know the difference between a condensing and a noncondensing turbine. You also know that you need cooling water to condense your steam. The amount of cooling water will vary with

a. the amount of steam that is to be condensed
b. the temperature of the steam at the condenser
c. the temperature of the cooling water

In this unit we will deal with how much water is needed to condense 1 pound of steam under given conditions, and then the total amount of water needed per hour to condense all the steam.

The formula for finding the number of pounds of circulating water needed per pound of steam is:

$$\frac{\text{Pounds of water}}{\text{Pound of steam}} = \frac{H_E - H_C}{t_1 - t_2}$$

Where H_E = enthalpy of exhaust steam
H_C = enthalpy of condensate
t_1 = temperature of circulating water leaving
t_2 = temperature of circulating water entering

Example 1: The condenser must handle 2000 pounds of steam per hour. The temperature of the condensate is 110°F., and the steam at the inlet to the condenser has a Btu content of 1023. The cooling-water inlet temperature is 70°; outlet temperature 100°F.

Find (A) Amount of water needed to condense 1 pound of steam

Find (B) Total amount of water needed per hour to condense 2000 pounds of steam

$$\frac{\text{Pounds of water}}{\text{Pounds of steam}} = \frac{H_E - H_C}{t_1 - t_2}$$

$$\text{Pounds of water}/_{\text{lb. steam}} = \frac{1023 - (110-32)}{100 - 70}$$

$$= \frac{1023 - 78}{30}$$

$$= \frac{945}{30} = 31.5$$

(A) 31.5 lbs. of water $/_{\text{lb. of steam}}$

$$\text{(B)}\quad \text{Total lbs. of water}/_{\text{hr}} = \text{lbs. of steam}/_{\text{hr.}} \times \text{lbs. of water}/_{\text{lb. of steam}}$$

$$= 2000 \times 31.5$$

$$= 63{,}000 \text{ lbs. of water}/_{\text{hr.}}$$

Example 2: A surface condenser must condense 3600 pounds of steam per hour. The steam has a heat content of 1022 Btu's per pound and the condensate temperature is 126°F. The circulating water enters at 60° F. and leaves at 75°F.

Find (A) amount of water needed to condense one pound of steam.

Find (B) amount of water needed per hour to condense all of the steam.

$$\text{(A)}\quad \text{lbs. of water}/_{\text{lb. of steam}} = \frac{H_E - H_C}{t_1 - t_2}$$

$$= \frac{1022 - (126 - 32)}{75 - 60}$$

$$= \frac{928}{15} = 61.9$$

(A) 61.9 lbs. of water $/_{\text{lb. of steam}}$

$$\text{(B)}\quad \text{lbs. of water}/_{\text{hr}} = \text{lbs. of steam}/_{\text{hr}} \times \text{lbs. of water}/_{\text{lb. of steam}}$$

$$= 3600 \times 61.9$$

$$= 222{,}840 \text{ lbs. of water}/_{\text{hr.}}$$

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Procedure: After studying the information and listed references, complete the following:

Assignment:

1. How much cooling water is needed to condense 1500 pounds of steam per hour if the temperature of the condensate is 100°F. and the steam at the inlet to the condenser has a Btu content of 1013. Cooling water at inlet, 60°F; at outlet, 70°F.

2. How much cooling water is needed to condense 3000 pounds of steam per hour if the temperature of the condensate is 130°F. and the steam at the inlet to the condenser has a Btu content of 1050. Cooling water at inlet, 70°F.; at outlet, 90° F.

3. How much cooling water is needed to condense 279,000 pounds of steam per hour if the temperature of the condensate is 126°F. and the steam at the inlet to the condenser has a Btu content of 1025. Cooling water: inlet 65°F.; outlet 75°F.

4. How much cooling water is needed to condense 175,000 pounds of steam per hour if the temperature of the condensate is 150°F. and the steam at the inlet to the condenser has a Btu content of 1006. Cooling water: inlet 80°F.; outlet 95°F.

5. How much cooling water is needed to condense 60,000 pounds of steam per hour if the temperature of the condensate is 115°F. and the steam at the inlet to the condenser has a Btu content of 1000. Cooling water: inlet 90°F.; outlet 110°F.

Objectives: Be able to state the purpose of an extraction steam turbine and a bleed steam turbine.

Be able to explain why these turbines are generally more efficient than other condensing or noncondensing turbines.

Information: The term "bleeder" and "extraction turbines" are used very loosely in the trade and are sometimes even used interchangeably. In this unit for clarity we will define **bleed steam** as steam withdrawn from a stage of turbine without pressure control. **Extraction** is the withdrawal of steam from a stage of a turbine that is under automatic pressure control.

Bleed steam is used for feed-water heating or constant-load use, such as you may find in a paper mill. It can be taken from one or more stages of a turbine and used for regenerative feed-water heating.

Extraction steam can be taken from one or more pressure stages of the turbine. The flow is controlled by a positioning control valve actuated by a servo-motor and connected to the governor system controlling the turbine speed. Extracted steam at various pressures is used for all types of steam process loads.

The big advantage of using bleed or extraction turbines is that you can utilize the heat in the steam rather than losing it to the condensing water or the atmosphere. The efficiency of these units can be very high if the proper balance between output load and the steam demand is maintained consistently.

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Procedure: After studying the information and the listed references, answer the following questions.

Assignment:

1. What is meant by the term "bleed steam"?

2. Where is bleed steam used?

3. What is meant by the term "extraction steam"?

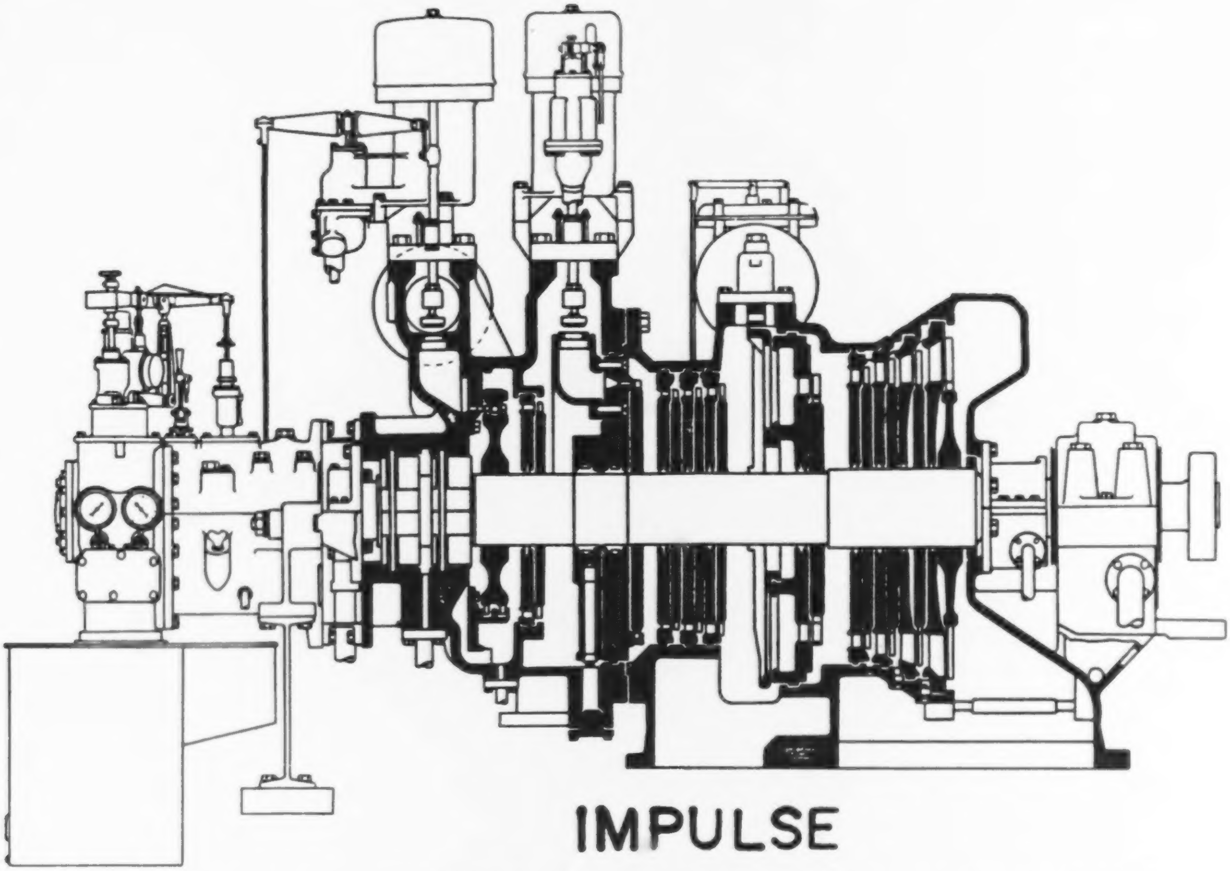
4. Where is extraction steam used?

5. How are bleed and extraction steam controlled?

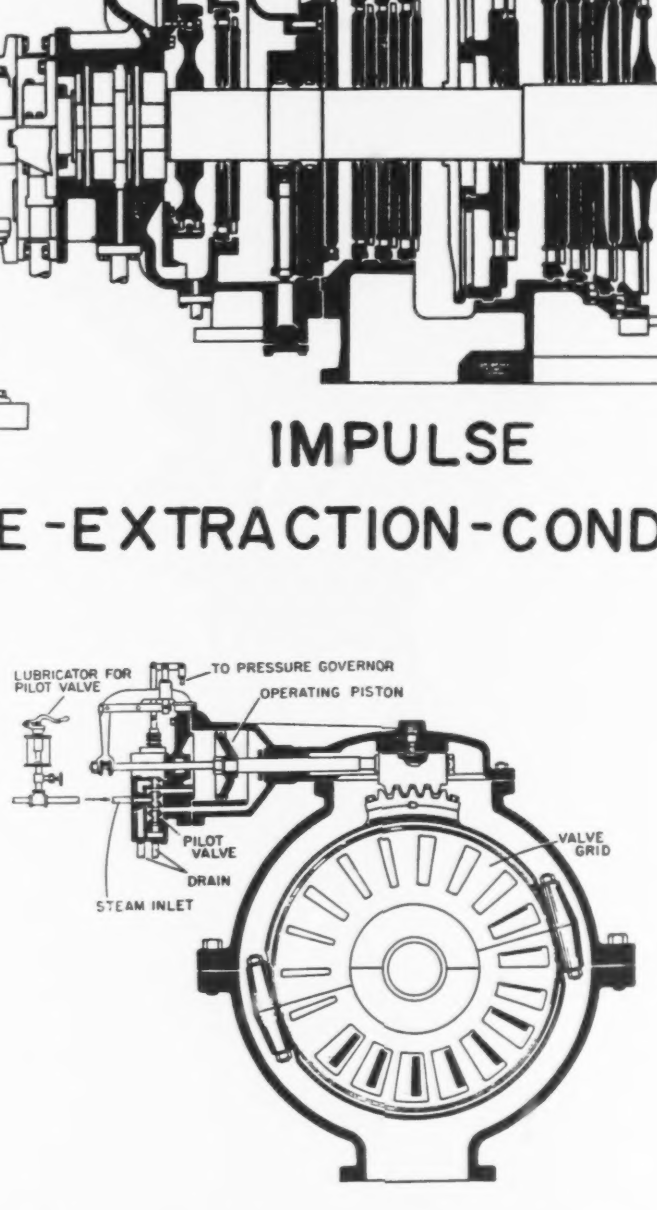
6. Why is it efficient to use bleed or extraction-type turbines?

7. Sketch the layout of a plant with an extraction turbine.

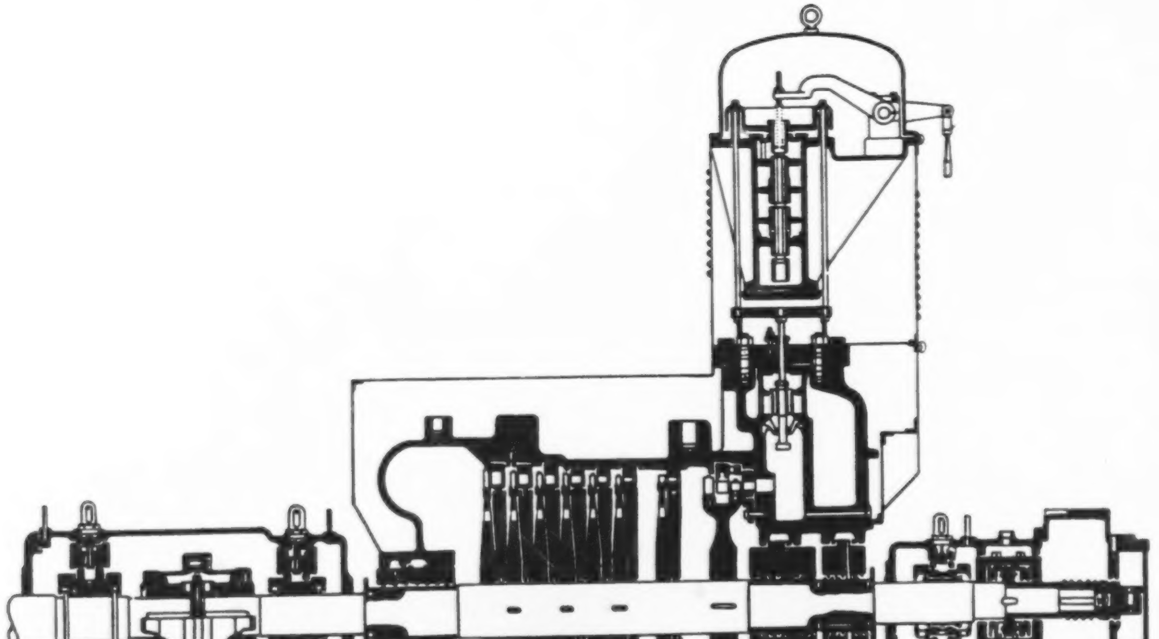
8. Sketch the layout of a plant that uses bleed steam for regenerative feed-water heating.



IMPULSE
DOUBLE-EXTRACTION-CONDENSING


LUBRICATOR FOR PILOT VALVE
TO PRESSURE GOVERNOR
OPERATING PISTON
VALVE GRID
PILOT VALVE
DRAIN
STEAM INLET

GRID EXTRACTION VALVE



IMPULSE

BLEED NONCONDENSING

Mechanical Governor — Assignment 12–H–1

Objectives: Be able to state the function of a mechanical speed-control governor and describe how it works.

Be able to state the function of an overspeed trip mechanism and describe how it works.

Information: With the steam turbine came the need for good speed control and overspeed tripping devices. The basic speed-control governor consists of a speed-control sensing element and linkage that controls the governor valve through the force acting on the speed-sensing element.

The usual speed-sensing element consists of weights mounted on the turbine shaft. The centrifugal force of the weights is opposed by springs which move the linkage of the governor valve toward the closed position. By having the sensing element and the governor valve connected, we can control the speed of the turbine.

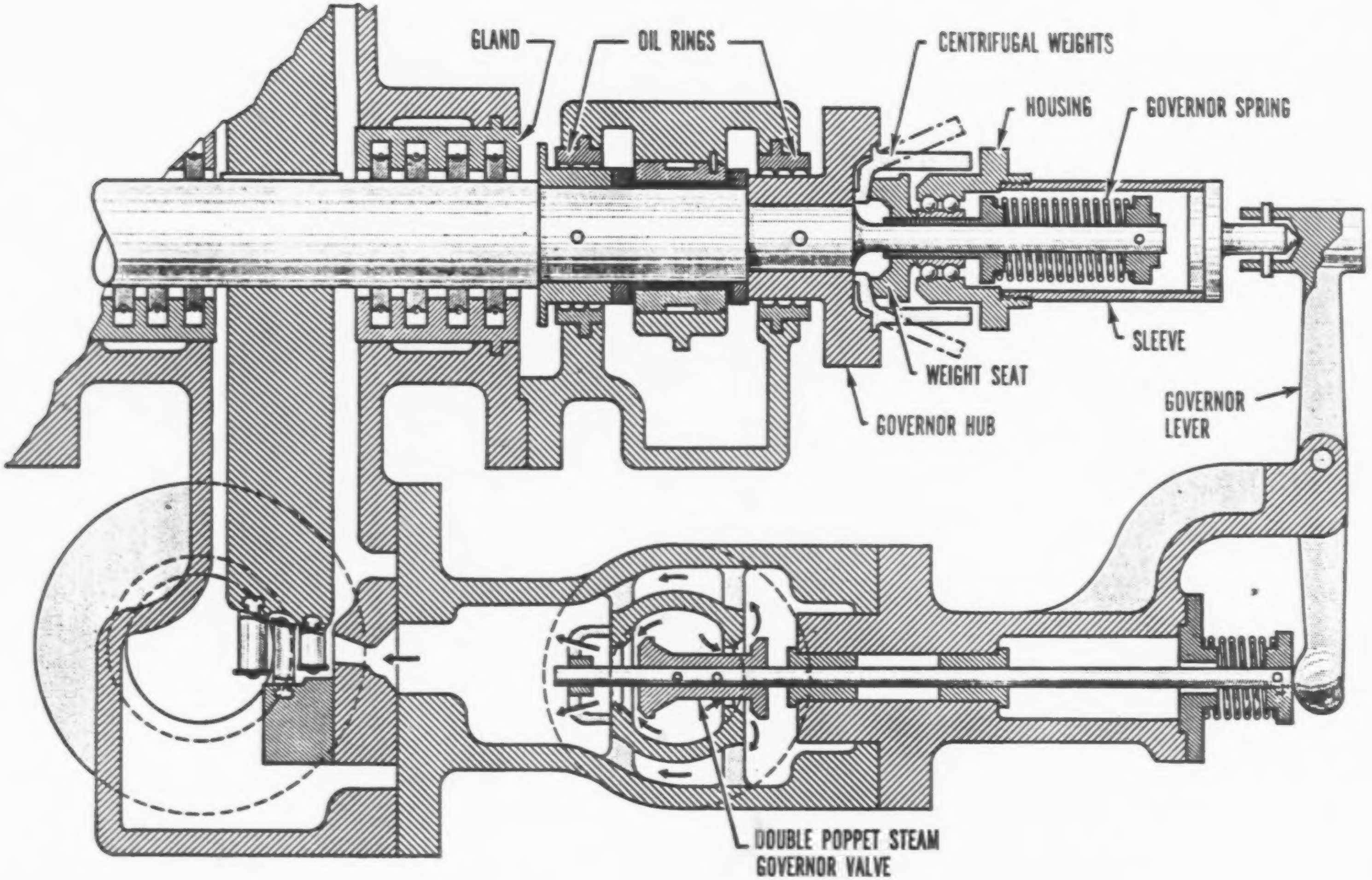
All governors must be designed for an adjustment of the speed during normal operation. This is done by having an adjusting spring on the linkage that can be tightened or loosened to change speed.

The overspeed trip is separate from the main governor but can limit the speed of the turbine in the following manner. A weight or bolt is mounted in the shaft and opposed by an adjustable spring. It remains in one position until the shaft speed reaches the point where the centrifugal force on the weight or bolt overcomes the spring tension. It then flies out and trips a latch device that releases a butterfly valve, closing off the steam supply.

Mechanical governors are used mainly on small auxiliary drives for pumps, fans, and compressors. They are not good for generating or where close control of speed is required. They are able to control the speed of the turbine within 2 to 3 percent of its rated speed.

References: *Elementary Steam Power Engineering*
Steam Plant Operation
Engineering Handbook

Procedure: After studying the above information and the listed references, answer the following questions.


GLAND
OIL RINGS
CENTRIFUGAL WEIGHTS
HOUSING
GOVERNOR SPRING
SLEEVE
WEIGHT SEAT
GOVERNOR HUB
GOVERNOR LEVER
DOUBLE POPPET STEAM GOVERNOR VALVE

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12-H-1-1

MECHANICAL GOVERNOR

Assignment:

1. What is the purpose of a mechanical governor?
2. Describe how a mechanical governor functions.
3. What are the advantages and disadvantages of a mechanical governor?
4. Describe how an overspeed trip functions.
5. With a line drawing, lay out a mechanical governor.

Rim Speed of Rotating Elements **Assignment 12–H–1–M1**

Objective: Be able to find the rim speed of a rotating element.

Information: A rotating element, such as a steam-turbine rotor, resists being moved in a circular path and builds up a centrifugal force which tends to pull the rotor apart. The centrifugal force developed depends upon the weight, velocity, and the radius of the rotating element. The opposite force needed to hold the element together in its circular path is known as the centripetal force.

For any given rotating element, the weight and radius will be constant, whereas the velocity of rim speed can vary. In this lesson we will learn how to determine the rim speed of any rotating element. The formula is:

$$\begin{aligned} \text{Rim speed} &= \text{circumference} \times \text{RPM} \\ &= \pi D \times \text{RPM} \\ &= 3.1416D \times \text{RPM} \end{aligned}$$

Example 1: A flywheel is 3 feet in diameter and is running at 300 RPM. Find the rim speed in feet per minute.

$$\begin{aligned} \text{Rim speed} &= \pi D \times \text{RPM} \\ &= 3.1416 \times 3 \times 300 \\ &= 2827 \text{ feet /min.} \end{aligned}$$

Example 2: Find the rim speed of the blading on a wheel of a turbine that runs at 3600 RPM and has a diameter of 18 inches.

$$\begin{aligned} \text{Rim speed} &= \pi D \times \text{RPM} \\ &= 3.1416 \times 1.5 \times 3600 \\ &= 16{,}965 \text{ feet/min.} \end{aligned}$$

Reference: *Engineering Handbook*

Procedure: After studying the information and the listed references, solve the following problems.

Assignment:

1. A flywheel is 3 feet in diameter and is running at 76 RPM. Find the rim speed in feet per minute.

2. A flywheel is 18 inches in diameter and is running at 120 RPM. Find the rim speed in feet per minute.

3. A flywheel is 60 inches in diameter and is running at 48 RPM. Find the rim speed in feet per minute.

4. The rim speed of a flywheel is 1257 feet per minute, and its diameter is 4 feet. Find the RPM.

5. The rim speed of a flywheel is 1885 feet per minute. Its RPM is 200. Find the diameter of the flywheel.

6. A turbine wheel 6 feet in diameter is rotating at 900 RPM. Find the rim speed.

7. A low-pressure element of a steam turbine is 4 feet in diameter. The machine is turning at 1800 RPM. What is the rim speed of the element?

8. What is the rim speed of a 3.5-foot diameter wheel that is moving at 3600 RPM?

9. What is the rim speed in miles per hour of the element in Question 7?

10. What is the rim speed in miles per hour of the wheel in question 8?

Objectives: Be able to explain how two different hydraulic governors function.

Be able to explain how an overspeed trip functions.

Be able to state the function of a low-oil trip mechanism.

Information: The hydraulic governor is very similar to the mechanical governor. It consists of a speed-sensing element and speed changer, but instead of linkage it has a servo-motor which amplifies the force to move the admission valves.

The Westinghouse oil-relay governor is a completely enclosed hydraulic system, using a single source of oil for governing and turbine lubrication. It has four essential elements, as follows:

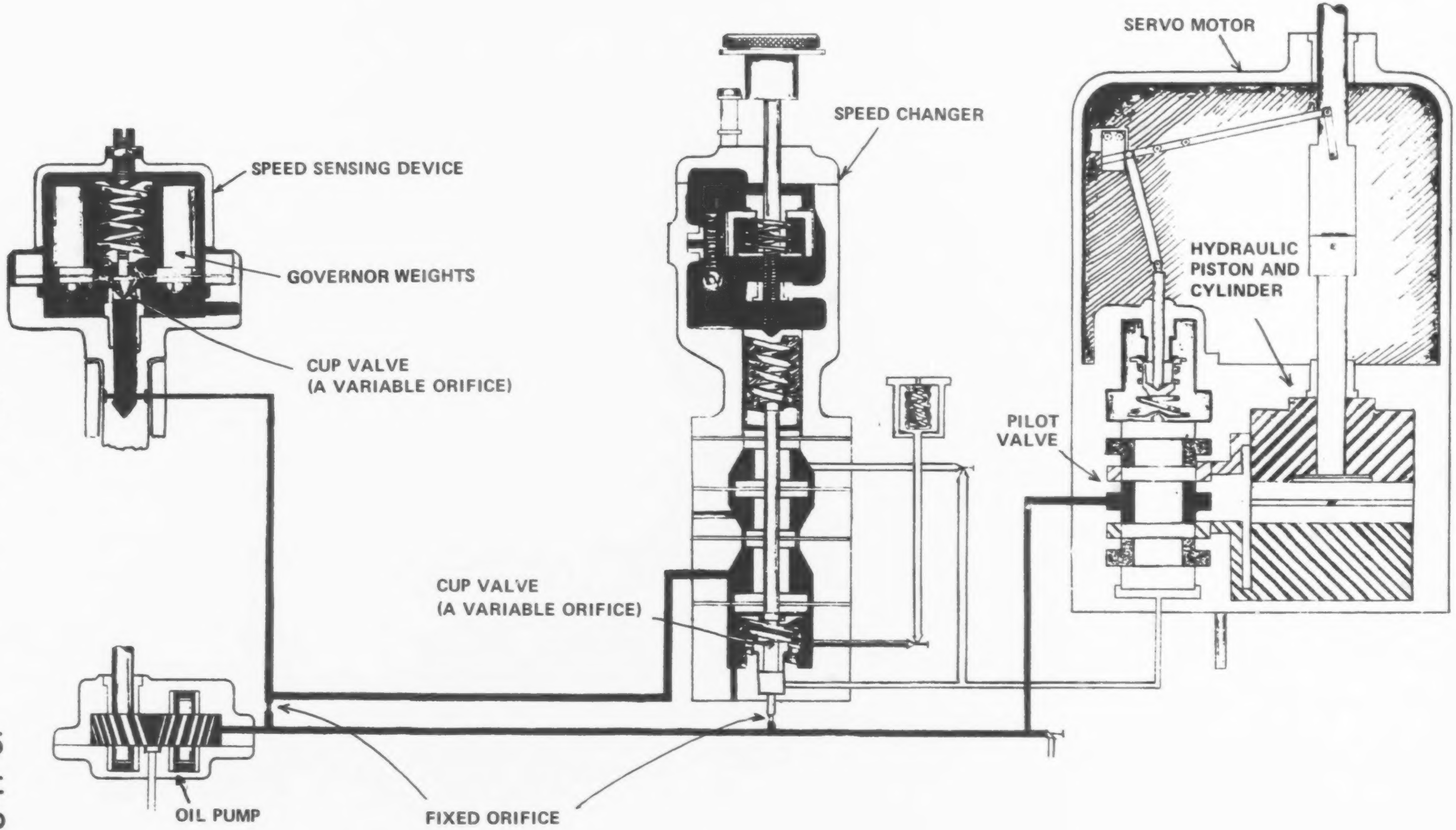
1. **Oil pump** for supplying oil for governing and lubrication.
2. Pair of **governor weights** secured to a spring-steel strap mounted across governor hub and driven from turbine rotor shaft. This is a so-called frictionless element, without wearing parts.
3. A **governing-oil valve,** which transforms changes in the force received from the governor weights into oil-pressure changes. In effect, it is a simple oil relief-valve, the pressure setting of which is dependent upon the turbine speed.
4. A **servo-motor,** which actuates the steam-admission valve in response to governing-oil pressure changes.

It operates in the following manner, as per Sketch 12–H–2–1.

The main oil pump supplies oil at constant high pressure for operation of the control apparatus. The small portion of oil used by the speed element enters below the governor cup-valve through a fixed orifice. A speed increase causes an increase of centrifugal force on the governor weights, which causes a decrease in governor-oil signal pressure, which causes the steam valve to move toward closed position.

The Westinghouse overspeed protection employs an overspeed detector that is entirely separate from the governor. It operates by centrifugal force and is triggered by a spring-held plunger in the governor end of the turbine shaft. At about 10% overspeed, it trips, and closes throttle valve.

WESTINGHOUSE OIL-RELAY GOVERNOR


SERVO MOTOR
SPEED CHANGER
SPEED SENSING DEVICE
GOVERNOR WEIGHTS
HYDRAULIC PISTON AND CYLINDER
CUP VALVE (A VARIABLE ORIFICE)
PILOT VALVE
CUP VALVE (A VARIABLE ORIFICE)
OIL PUMP
FIXED ORIFICE

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12-H-2-1

The G.E. oil-relay governor is also a completely enclosed hydraulic system but uses separate oil pumps for lubrication and governor control. It operates as follows (Refer to Sketch 12–H–2–2).

Speed is controlled by a centrifugal governor using an oil-operated valve gear to control the speed by cutting out nozzles of the first stage. The speed governor is of the centrifugal fly-ball type. The oil for operating the governor is supplied by an oil pump driven from the same secondary shaft that drives the governor. Movement of the governor positions the pilot valve controlling the flow of oil to and from the primary relay.

As the speed changes, the governor moves the pilot valve that controls the oil to the primary relay cylinder, which moves connecting levers controlling secondary relay apparatus, thus opening or closing steam-admission valves.

The emergency governor is entirely separate from the main governor's valve system. It consists of a chamber in which a bolt and controlling spring are mounted in an extension of the main shaft. A speed increase of 10 percent above normal increases centrifugal force enough to cause the bolt to strike a trip, releasing the latch that holds the throttle valve open.

The G.E. and Westinghouse hydraulic governors have these two features in common:

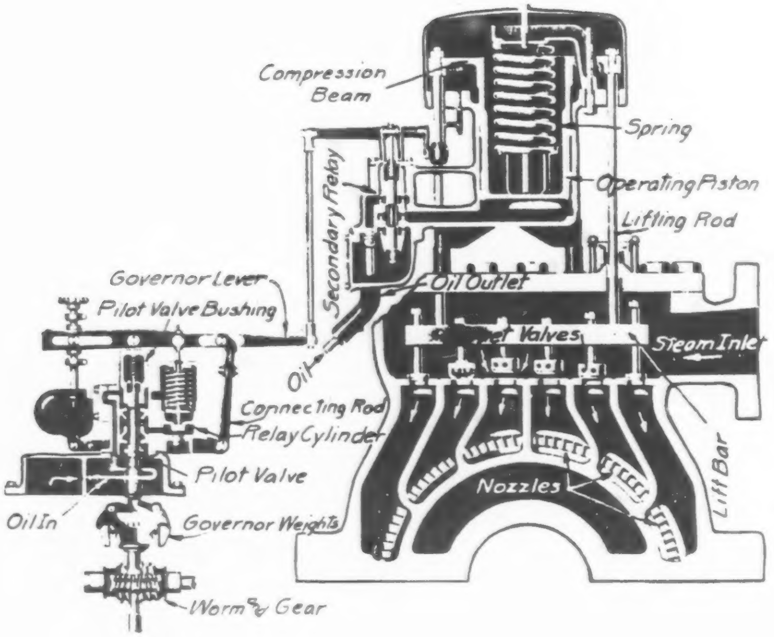
1. The flow of steam to turbine may be regulated to maintain constant speed.
2. In addition to the speed-regulating governor, there are protective emergency devices entirely independent of the governor. These shut off the steam to the turbine by causing throttle valves, located in the steam line ahead of the steam-control valve, to trip. These function to protect the turbine from overspeed or low oil.

References: *Steam Plant Operation*
Elementary Steam Power Engineering
Engineering Handbook

Procedure: After studying the above information and the listed references, answer the following questions.

Assignment:

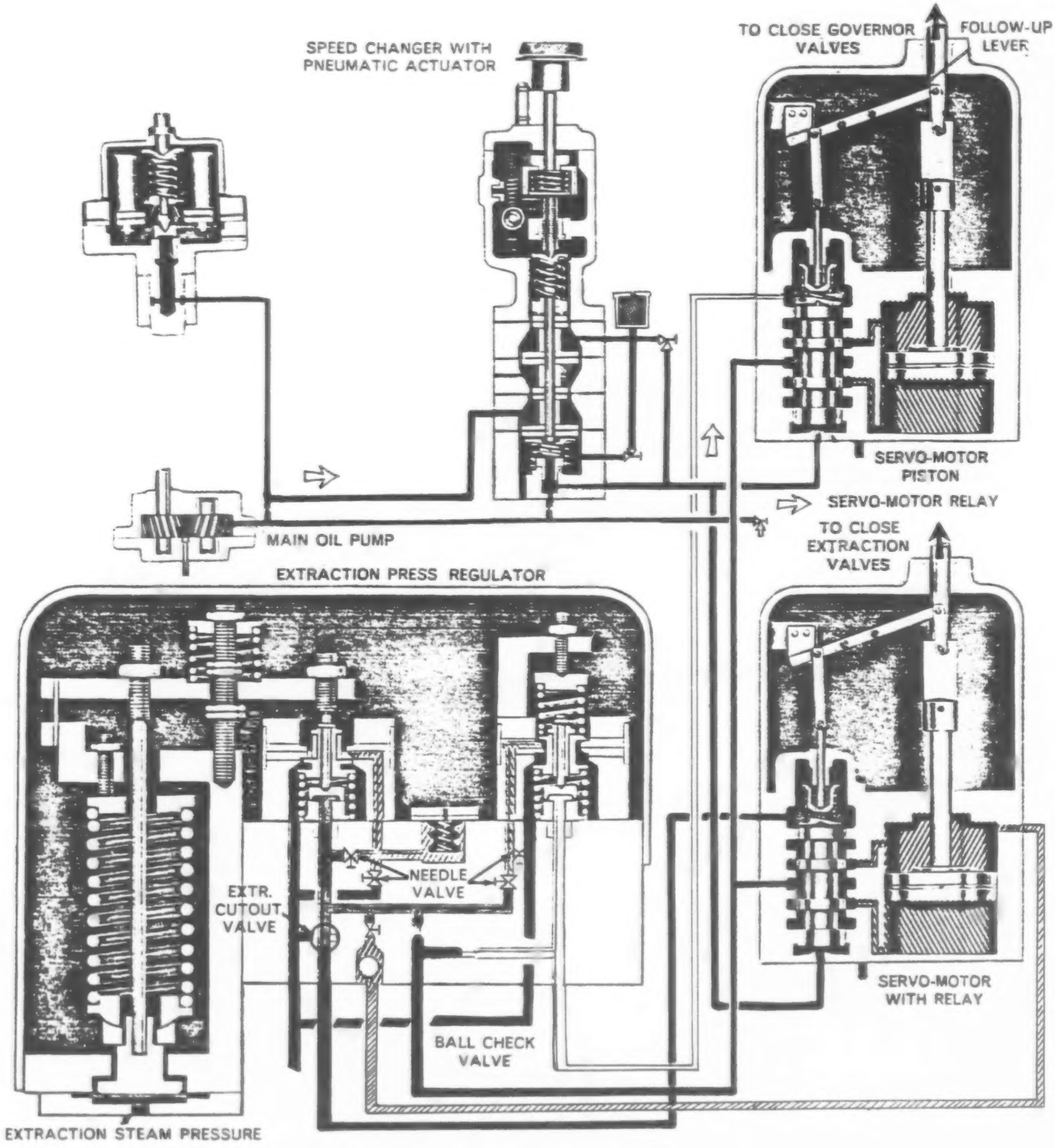
1. List the parts of a G.E. hydraulic governor.


Compression Beam
Spring
Operating Piston
Lifting Rod
Secondary Relay
Governor Lever
Pilot Valve Bushing
Oil Outlet
Valves
Steam Inlet
Oil
Connecting Rod
Relay Cylinder
Pilot Valve
Oil In
Governor Weights
Nozzles
Lift Bar
Worm & Gear

G.E. OIL-RELAY GOVERNOR

2. Describe how the G.E. governor functions.
3. List the parts of a Westinghouse hydraulic governor.
4. Describe how the Westinghouse governor functions.
5. What safety devices are there to control overspeed and low oil pressure?
6. Make a line drawing of the G.E. and Westinghouse hydraulic governors.

WESTINGHOUSE
GOVERNOR WITH EXTRACTED STEAM


SPEED CHANGER WITH PNEUMATIC ACTUATOR
TO CLOSE GOVERNOR VALVES
FOLLOW-UP LEVER
SERVO-MOTOR PISTON
SERVO-MOTOR RELAY
MAIN OIL PUMP
TO CLOSE EXTRACTION VALVES
EXTRACTION PRESS REGULATOR
NEEDLE VALVE
EXTR. CUTOUT VALVE
SERVO-MOTOR WITH RELAY
BALL CHECK VALVE
EXTRACTION STEAM PRESSURE

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12-H-2-3

Objective: Be able to state types and purpose of lubricants, how they differ, and how to select suitable ones for different jobs.

Information: You have heard the expression "the squeaking wheel gets the grease." Well it's true, but we have come a long way from that slow-moving squeaking wheel.

Modern equipment with high temperatures and speeds of up to 3600 RPM have put quite a demand on lubrication technology. Lubrication is no longer a hit-and-miss, "that's a good enough oil to use" type of business. The operator must know the equipment and then make the correct selection of lubricant.

You do not use the same type of oil for a reciprocating engine, a turbine, and an air compressor. Why not? Because their operating characteristics are different.

The reciprocating engine uses saturated steam, and the cylinder oil comes in contact with the steam and condensate.

The steam turbine turns at a high RPM, uses superheated steam, and has a pressurized-oil system. The oil does not come in contact with the steam. The entire rotor rests on a film of oil – lose your oil and chances are you have lost your turbine rotor!

The air compressor in compressing air builds up a very high temperature. Oil that gets into the cylinders through worn rings could very easily lead to an explosion. It would act much like a diesel engine.

From these examples you should certainly see the importance of the proper selection of lubricants. The oil companies are continually striving for a better product. Call them and they will send someone in to survey your plant and tell you what you need for each piece of equipment. The companies also put out manuals suggesting types of lubricants and frequency of lubrication.

Lubrication is a very important part of efficient plant operation. Establishing a lubrication schedule will increase the life of your equipment and cut down on equipment downtime. It has been stated that friction losses can steal 4 to 20 percent of the total power developed by an engine.

Lubricants may be classified as:

1. solid – graphite
2. semi-solid – greases
3. liquid – oil

Methods of lubrication

1. Individual bearings
   a) Hand
   b) Drop-feed
   c) Ring
   d) Wiper
   e) Cup
   f) Oil-waste
2. Group bearings
   a) Splash
   b) Gravity circulating
3. Cylinder lubrication
   a) Hydrostatic lubricator
   b) Mechanical lubricator

References: *Steam Plant Operation*
Elementary Steam Power

Procedure: After reading the information above and studying the listed references, answer the following questions and be prepared to discuss each.

Assignment:

1. What is the purpose of using lubication?

2. What qualities must a lubricant have?

3. What procedure would you follow in selecting a lubricant for a specific job?

4. How are lubricants classified?

5. What are basic methods of lubrication?

6. a) What purpose do detergents in the oil serve?
   b) What is the purpose of a wetting agent?
   c) What is the purpose of compounding mineral oil with vegetable oil?

7. a) What is viscosity?
   b) Would you select a high- or low-viscosity oil for a high-speed engine? Why?

8. a) What is a hydrostatic lubricator?
   b) How does it operate?
   c) How is it refilled?

9. What two methods are used to recondition low-viscosity lubricating oil?

10. a) What is a forced-feed lubricator?
    b) How does it operate?

Objective: Be able to describe the basic types of lubrication systems found on steam turbines.

Information: The operation of an entire plant can depend upon the proper functioning of a turbine that is used as a prime mover. This is why turbines must be provided with lubrication systems that assure a reliable supply of lubricating oil for all bearing surfaces.

Turbines that are used to drive auxiliary equipment are usually small units that use ring-oiling, gravity, or hand-feed oiling systems. **Ring oiling** consists of a ring around the bearing journal that rotates when the machine is in operation and carries oil onto the bearing surface from a reservoir below. There is sometimes a cooling-water coil in the reservoir to remove heat from the lubricating oil. **Gravity feed** is used on small turbines – a cup is filled with oil, and the oil feed is regulated by a valve setting. The amount of oil going to the bearing surface can be observed through a sight glass. In the **hand-feed** system, oil is applied using a hand oil can.

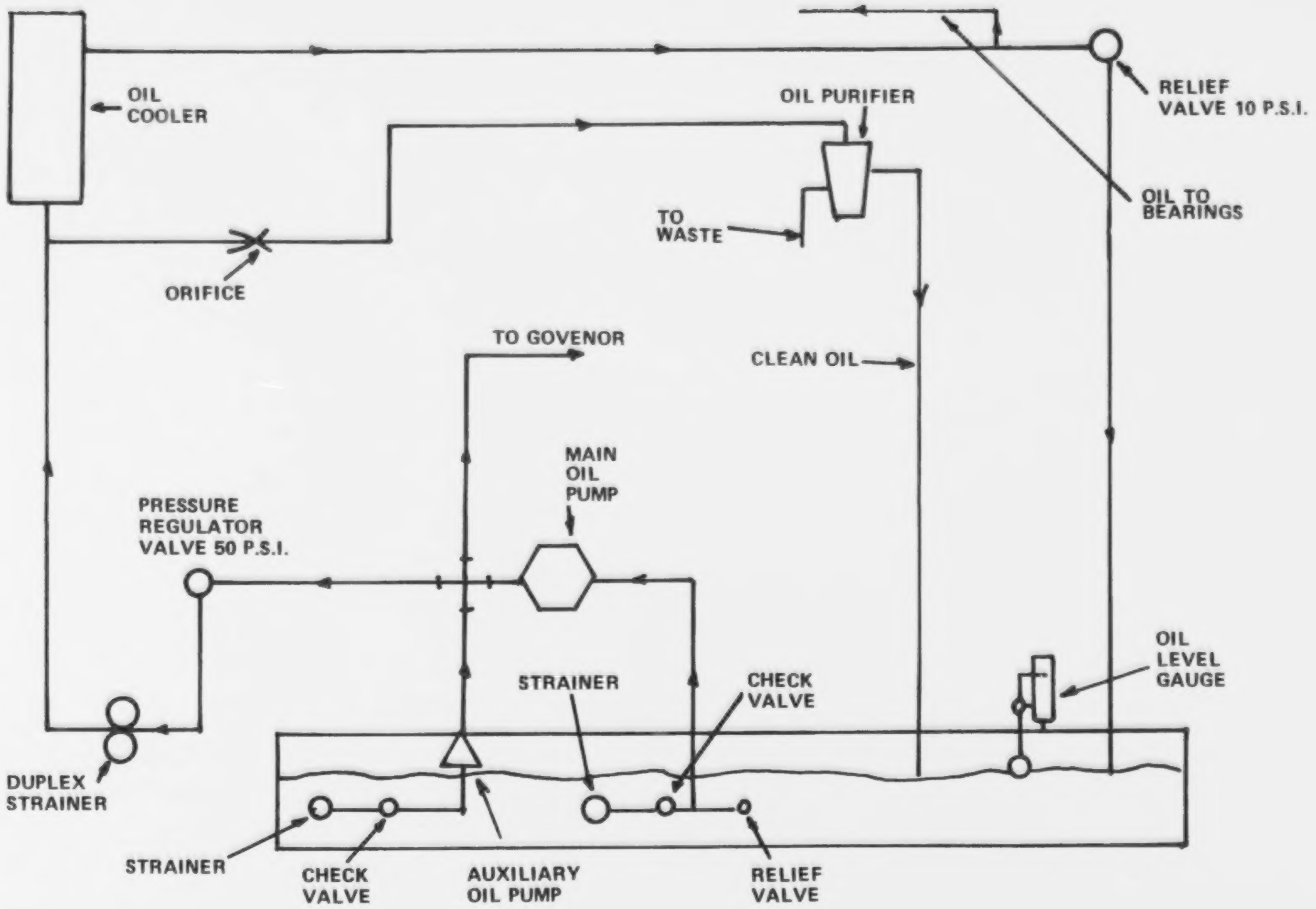
Large turbines are equipped with a **forced-circulation** oil system. This system contains at least two oil pumps, one of which is driven off of the main shaft and an auxiliary oil pump that is usually steam-driven. There is a reservoir of oil with some type of purification system attached. Also there has to be a lubrication-oil cooler, and water is the usual coolant. This oil system supplies oil to the main bearings of the generator and turbine, including the thrust bearing. The governor oil is also taken from this system, which also supplies oil to the overspeed and low-oil-pressure safety trips.

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Procedure: After studying the above information and the listed references, complete the following assignment.

Assignment:

1. What types of lubrication systems are found on steam turbines?
2. Describe each type in detail.
3. Why is the lubrication system on a turbine so important? Explain.
4. For what purpose other than lubrication is the lubrication oil used?
5. Make a line drawing of a force-feed lubrication system. Include all components.


OIL COOLER
OIL PURIFIER
RELIEF VALVE 10 P.S.I.
TO WASTE
OIL TO BEARINGS
ORIFICE
TO GOVENOR
CLEAN OIL
MAIN OIL PUMP
PRESSURE REGULATOR VALVE 50 P.S.I.
OIL LEVEL GAUGE
STRAINER
CHECK VALVE
DUPLEX STRAINER
STRAINER
CHECK VALVE
AUXILIARY OIL PUMP
RELIEF VALVE

13-B-1-1

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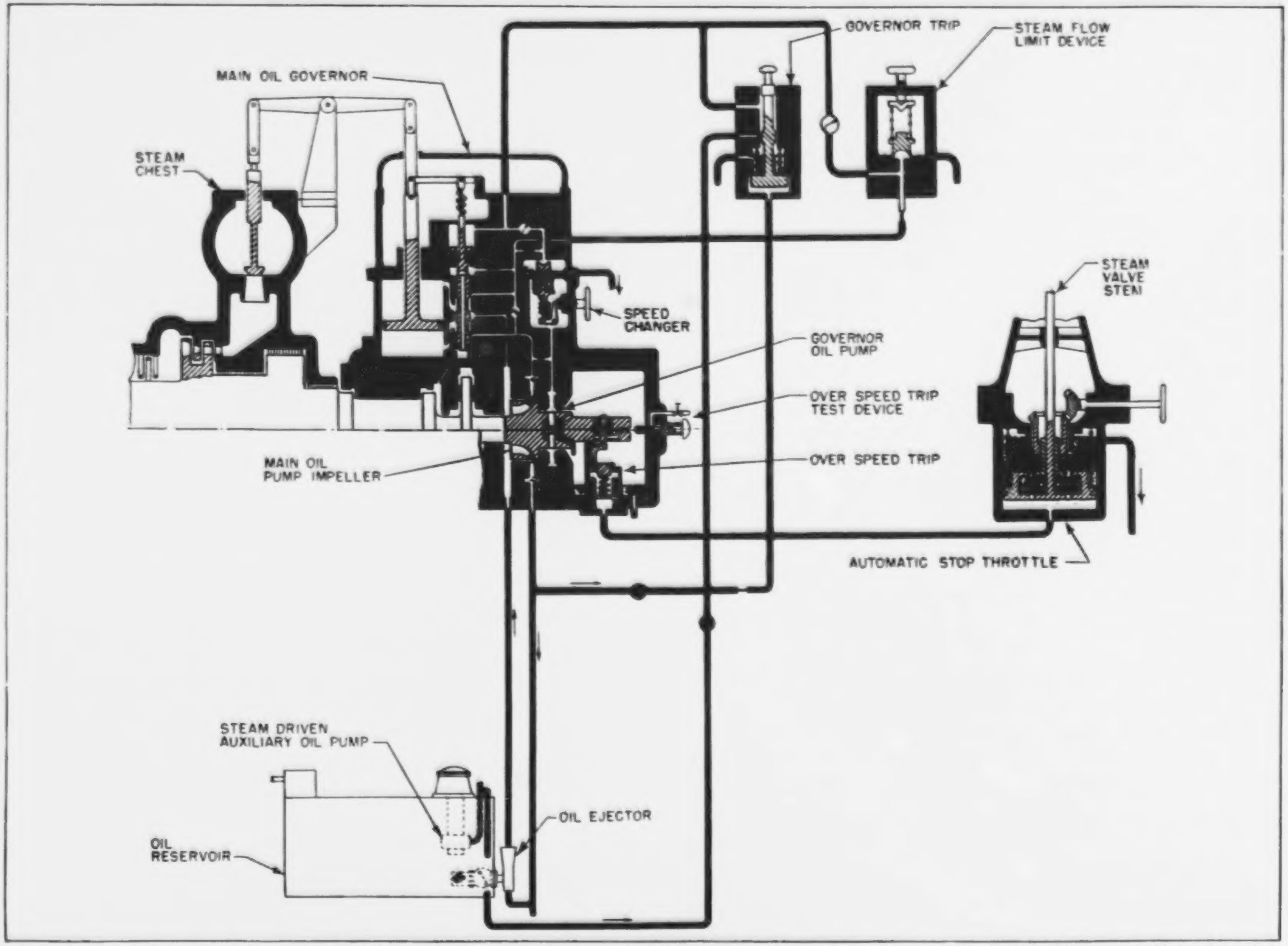
CLOSED LUB. OIL SYSTEM

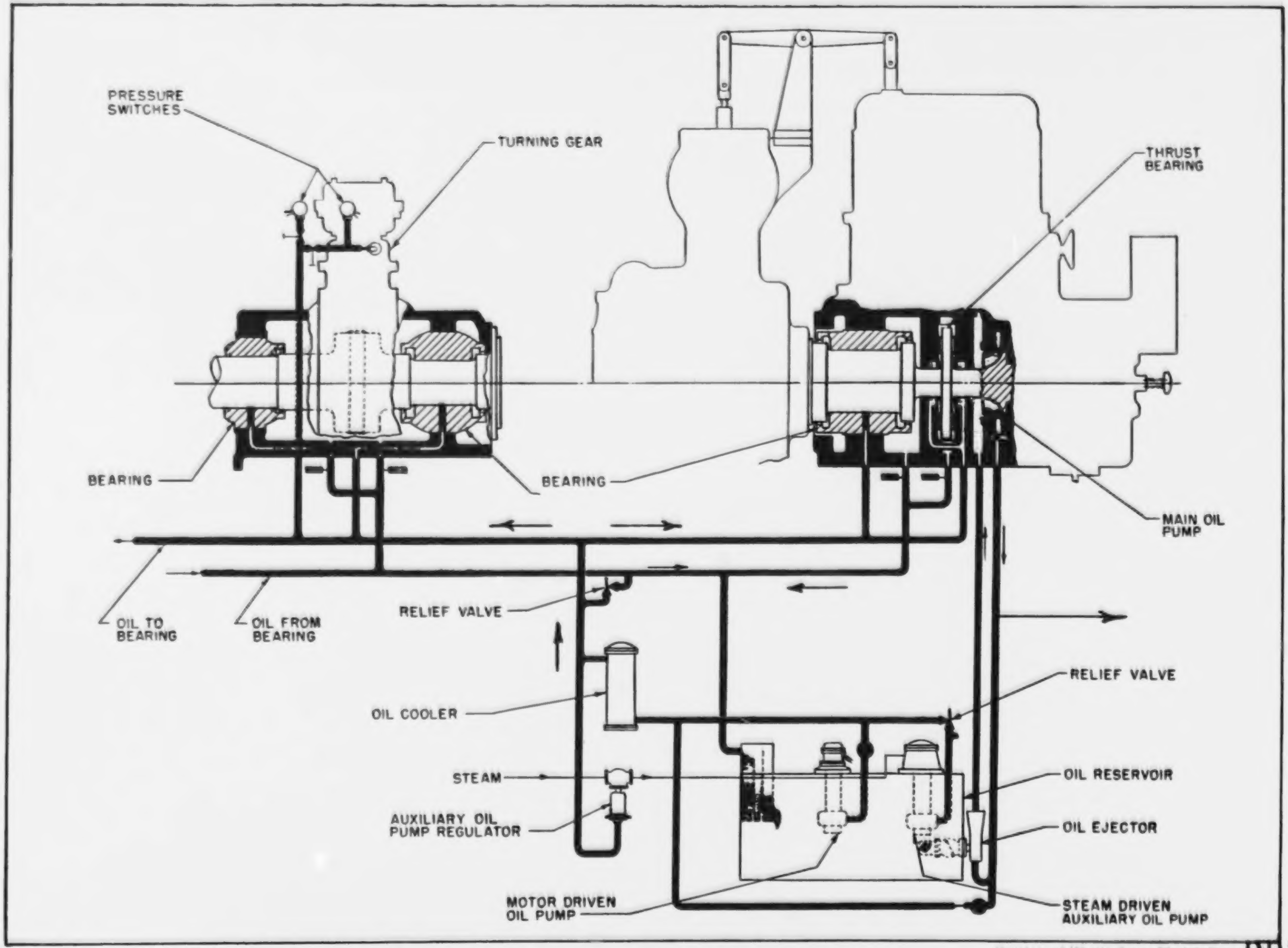
288

13-B-1-2


MAIN OIL GOVERNOR
GOVERNOR TRIP
STEAM FLOW LIMIT DEVICE
STEAM CHEST
SPEED CHANGER
STEAM VALVE STEM
GOVERNOR OIL PUMP
OVER SPEED TRIP TEST DEVICE
MAIN OIL PUMP IMPELLER
OVER SPEED TRIP
AUTOMATIC STOP THROTTLE
STEAM DRIVEN AUXILIARY OIL PUMP
OIL EJECTOR
OIL RESERVOIR

Courtesy of Westinghouse Electric Corporation

CONTROL-OIL SYSTEM FOR
A WESTINGHOUSE STEAM TURBINE


PRESSURE SWITCHES
TURNING GEAR
THRUST BEARING
BEARING
BEARING
MAIN OIL PUMP
OIL TO BEARING
OIL FROM BEARING
RELIEF VALVE
RELIEF VALVE
OIL COOLER
STEAM
AUXILIARY OIL PUMP REGULATOR
OIL RESERVOIR
OIL EJECTOR
MOTOR DRIVEN OIL PUMP
STEAM DRIVEN AUXILIARY OIL PUMP

Courtesy of Westinghouse Electric Corporation

LUBRICATING OIL SYSTEM FOR A WESTINGHOUSE STEAM TURBINE

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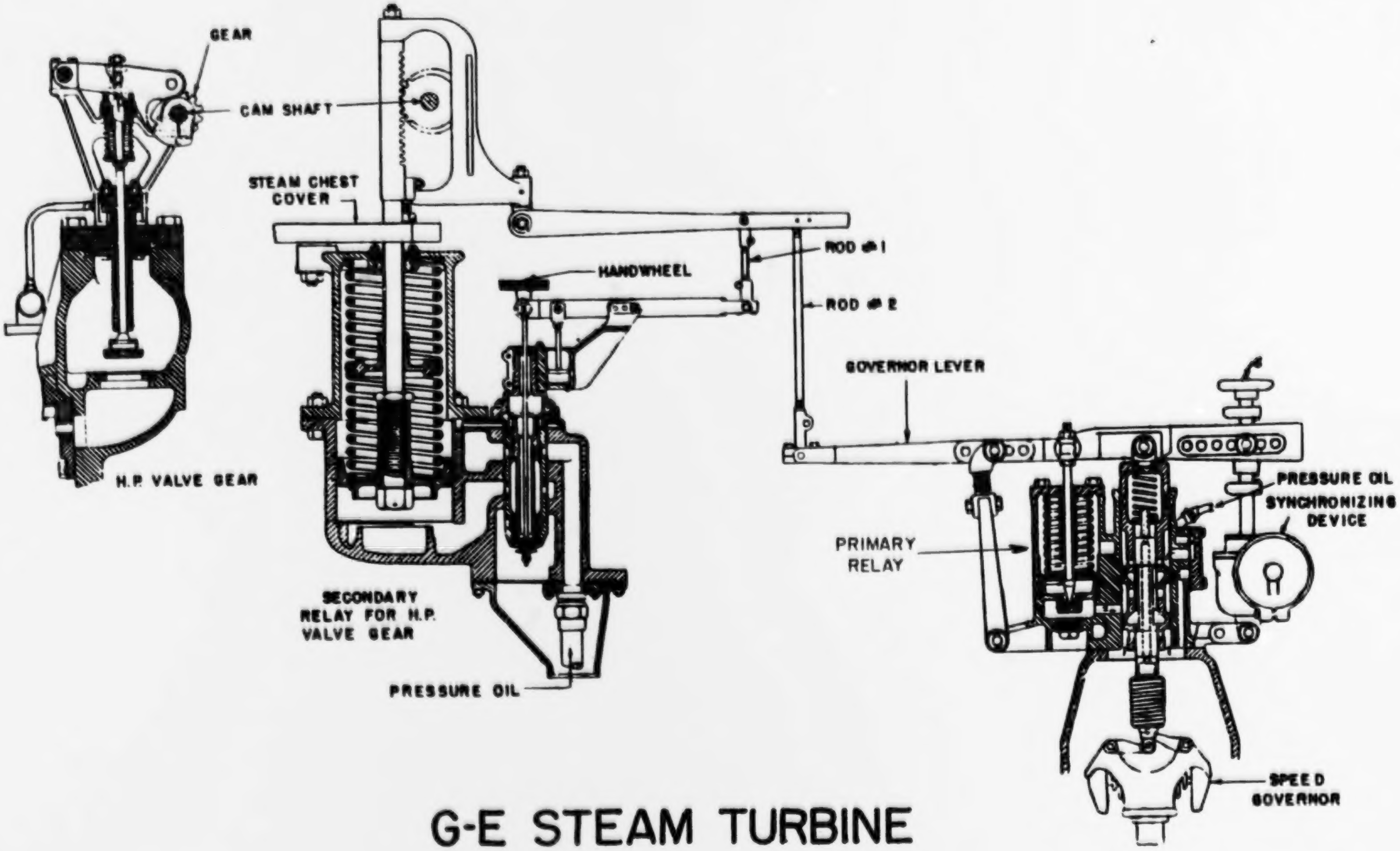
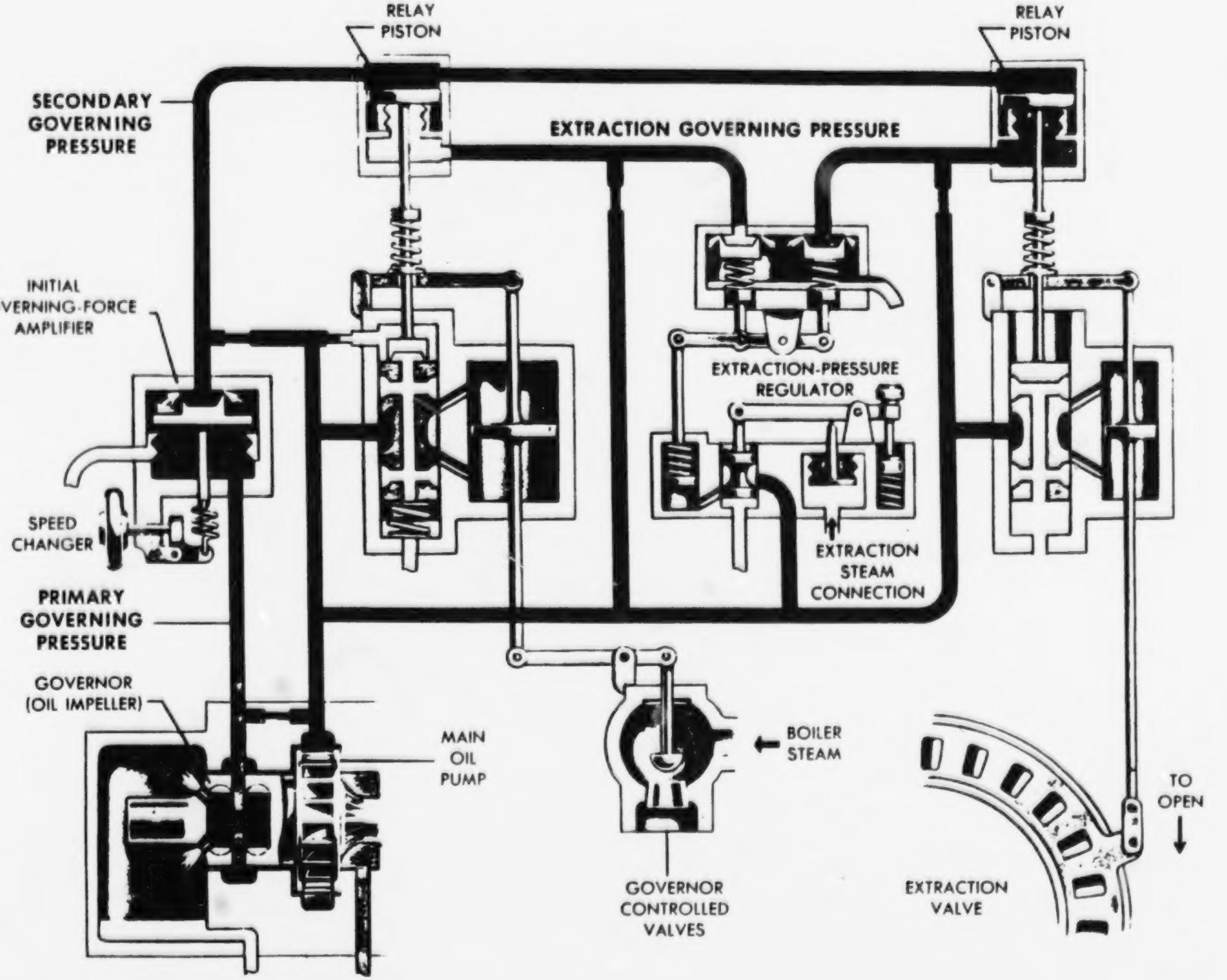
13-B-1-3


GEAR
CAM SHAFT
STEAM CHEST COVER
HANDWHEEL
ROD #1
ROD #2
GOVERNOR LEVER
H.P. VALVE GEAR
PRESSURE OIL
SYNCHRONIZING DEVICE
PRIMARY RELAY
SECONDARY RELAY FOR H.P. VALVE GEAR
PRESSURE OIL
SPEED GOVERNOR

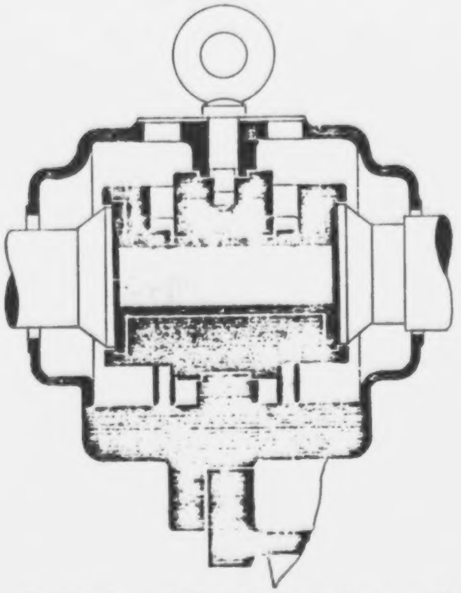
G-E STEAM TURBINE

13-B-1-4

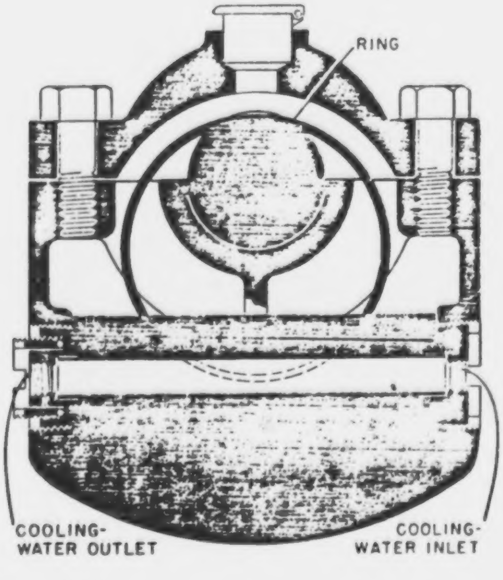
SINGLE-EXTRACTION CONTROL


RELAY PISTON
RELAY PISTON
SECONDARY GOVERNING PRESSURE
EXTRACTION GOVERNING PRESSURE
INITIAL GOVERNING-FORCE AMPLIFIER
EXTRACTION-PRESSURE REGULATOR
SPEED CHANGER
EXTRACTION STEAM CONNECTION
PRIMARY GOVERNING PRESSURE
GOVERNOR (OIL IMPELLER)
MAIN OIL PUMP
BOILER STEAM
TO OPEN
GOVERNOR CONTROLLED VALVES
EXTRACTION VALVE

13-B-1-5



PRESSURE-FED JOURNAL BEARING


RING
COOLING-WATER OUTLET
COOLING-WATER INLET

RING-FED BEARING

Objectives: Be able to explain why purification systems are needed.

Be able to describe the different types of purification systems available and tell how they function.

Information: It has become a fairly standard practice to discard the oil in your car every 3,000 miles and replace it with new oil, and then to change the filter and oil again at 6,000 miles. This is necessary to increase the life expectancy of your car's motor – not a bad idea when you are only talking of 6 to 8 quarts of oil.

But what about 100 to 500 gallons of oil? Not a very pretty picture dollarwise, is it? Not when you pay at least double for turbine lubricating oil.

Well, the engineers sat down and after much work came up with a few solutions. First of all they knew that turbine oils are extremely high quality oils and have a long life. The problem is that oil picks up dirt and other contaminants from its contact with the steam, and these contaminants have to be removed. They developed two basic methods:

1. Continuous or by-pass method
2. Batch method

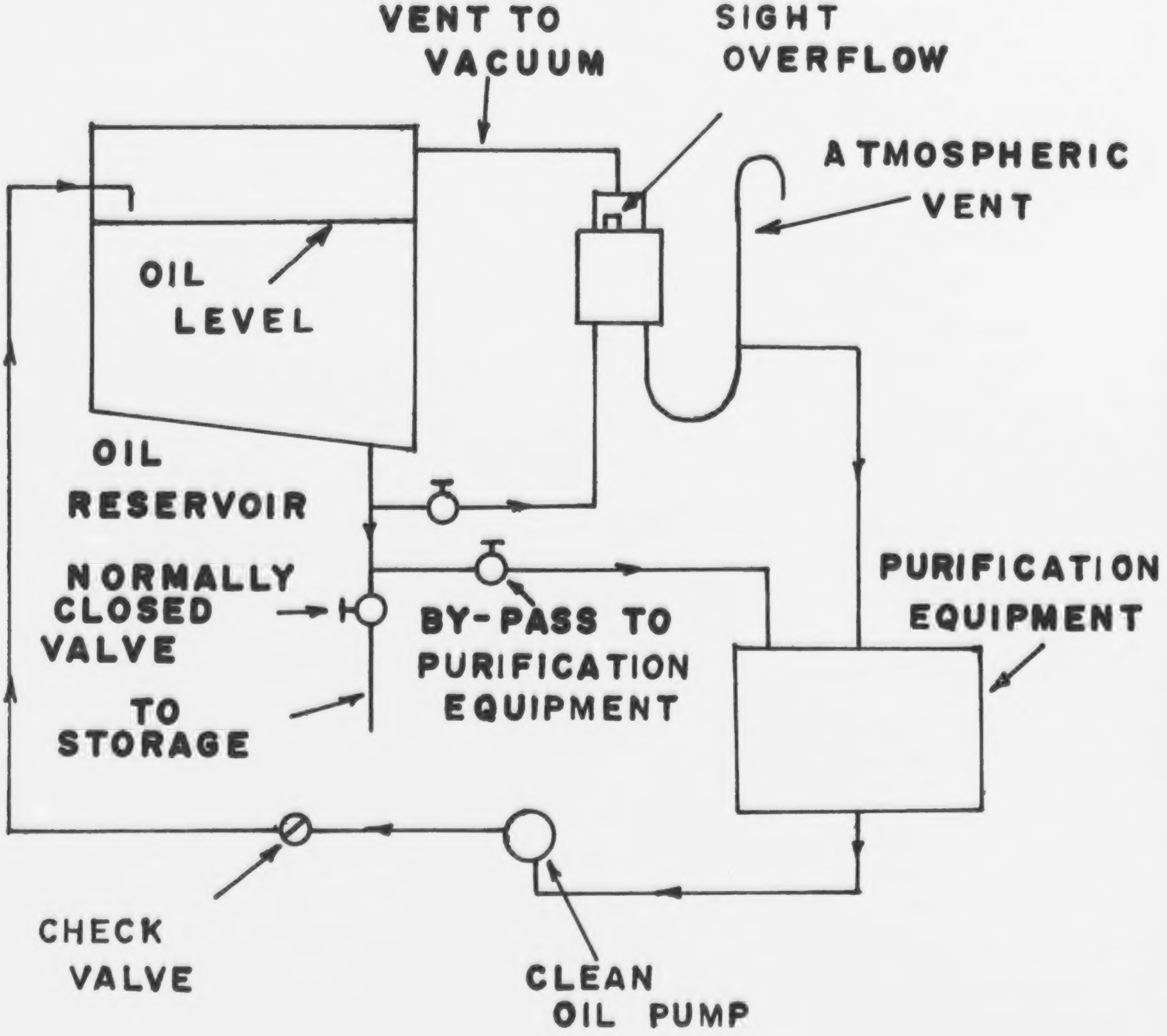
Let's look at them one at a time.

Continuous or by-pass system

The system is usually operated when the turbine is running, although if necessary it can be run when the turbine is down due to high levels of contamination. Fig. 13–B–2–1 shows a schematic of the system. The oil to be purified is continuously being taken from the lowest part of the turbine oil reservoir to the purification equipment. This could consist of filters, a centrifuge, or a combination of these, or it could be a combination of settling and filtration.

Batch purification (Fig. 13–B–2–2)

Here the oil is withdrawn from the turbine after shutdown, before the oil has had a chance to cool off completely. It will then be put through a centrifuge, a filter, or a combination of these. In some plants there will be two large holding tanks. One will have a supply of clean oil, and the other will hold the oil that has just been removed from the turbine.


VENT TO VACUUM
SIGHT OVERFLOW
ATMOSPHERIC VENT
OIL LEVEL
OIL RESERVOIR
NORMALLY CLOSED VALVE
TO STORAGE
BY-PASS TO PURIFICATION EQUIPMENT
PURIFICATION EQUIPMENT
CHECK VALVE
CLEAN OIL PUMP

CONTINUOUS - PURIFICATION SYSTEM

13-B-2-1

The procedure would be to remove used oil from the turbine sump to the #2 holding tank. Clean turbine sump. Fill sump from Tank #1. Then by gravity drop oil from #2 tank through a centrifuge, and the clean oil goes back into tank #1. This requires that two full charges of oil be in service. This oil would be changed over after so many hours of running time, which would be established by the turbine manufacturer or plant conditions.

Some engineers feel the continuous purification system is superior to the batch system, because it is able to hold the contamination level of the oil at a low point.

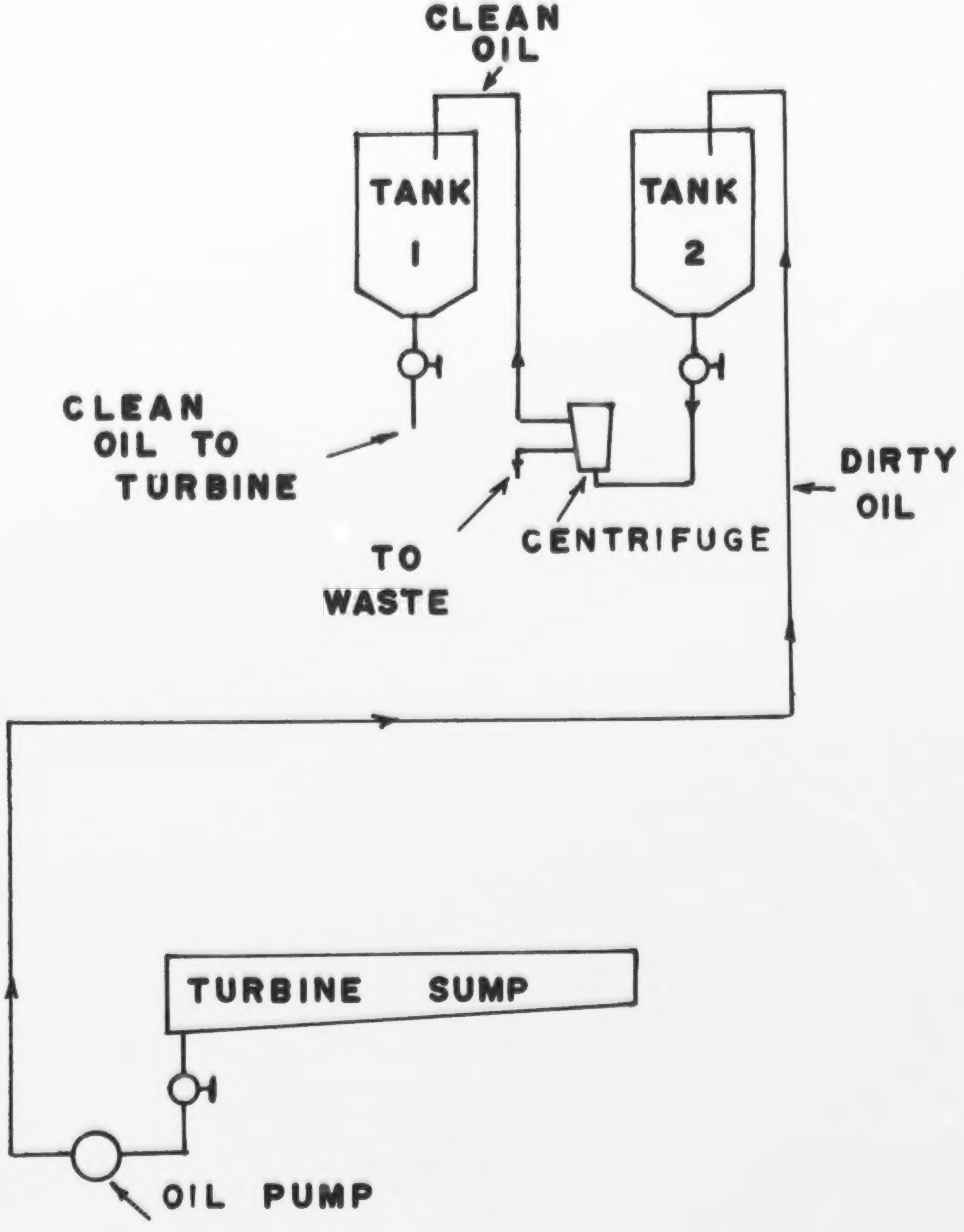
Fig. 13—B—2—3 is a schematic of a batch system using settling tanks for purification.

References: *Steam Turbines and Their Lubrication* (Mobil Oil Co.)
Stationary Steam Turbines and Their Lubrication (Socony-Vacuum)
Steam Turbine Lubrication (Vacuum Oil Co.)

Procedure: After studying the listed references, answer the following questions and be prepared to discuss each in class.

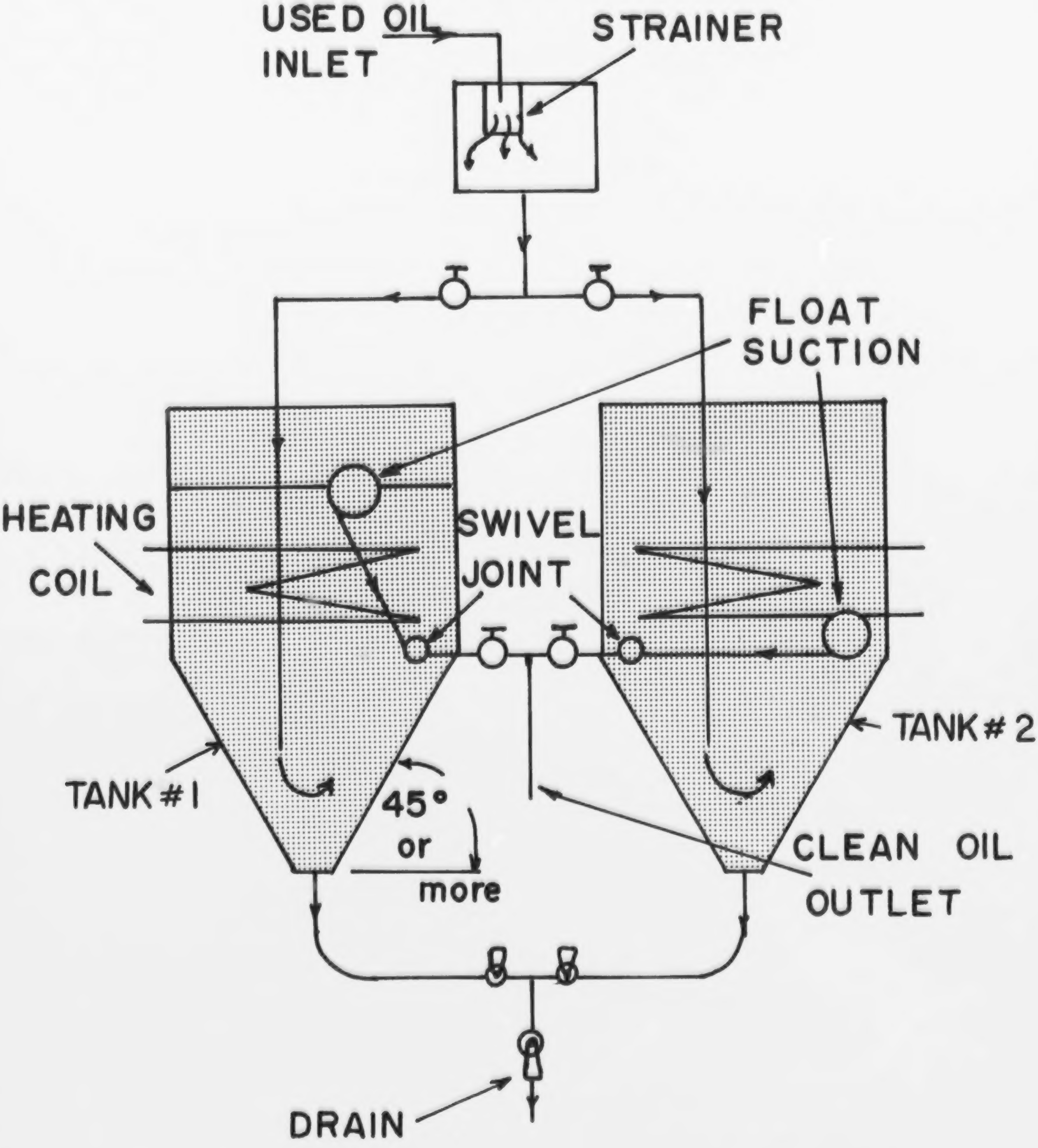
Assignment:

1. What are the two general classes of lubrication systems?
2. Describe how each functions.
3. What principles are employed in turbine-oil purification?
4. Briefly discuss each.
5. State three different ways of purifying contaminated oil.


CLEAN OIL
TANK 1
TANK 2
CLEAN OIL TO TURBINE
TO WASTE
CENTRIFUGE
DIRTY OIL
TURBINE SUMP
OIL PUMP

BATCH SYSTEM CENTRIFUGE

BATCH SYSTEM SETTLING


USED OIL INLET
STRAINER
FLOAT SUCTION
HEATING COIL
SWIVEL JOINT
TANK # 2
TANK # 1
45° or more
CLEAN OIL OUTLET
DRAIN

13-B-2-3

Objective: Be able to start up a generating plant.

Be able to shut down a generating plant.

Information: When starting up a generating plant, the boiler room has to be prepared first. This involves getting a boiler ready and on the line. Once the boiler room is ready, the main steam line to the turbo-generator should be warmed up, and all condensate removed through a free-flowing drain. The warming up can be done by cracking the by-pass around the main steam-stop valve going to the turbine. This step is very important, because you do not want to have moisture striking the turbine blades even on startup.

As soon as you have completed the warmup, you should then follow the turbine manufacturer's recommendations on startup. A suggested procedure would be as follows:

1. Start auxiliary oil pump and check oil pressure.
2. Check level in oil reservoir.
3. Check cylinder drain valves – to be in open position.
4. Open gland leak-off valves.
5. Drain condensate from and admit steam to main steam header up to throttle valve.
6. Establish circulating water-flow through condenser.
7. Establish seal on HP and LP ends for starting.
8. Admit enough steam to start rotor and then shut it off.
9. Listen for rubs on casing and seal locations.
10. If no rubs are heard, admit enough steam to maintain 200 RPM for ½ hour, to warm casing and rotor evenly.
11. Turn on cooling water to oil cooler to maintain 100°F. outlet oil temperature.
12. Close cylinder drains.
13. Adjust HP and LP seals for operating condition.
14. Start condensate pump.
15. Seal atmospheric valve.
16. Start air ejectors.
17. Bring turbine slowly up to rated speed.
18. Trip turbine emergency control to check operation.
19. Reset trip. Bring turbine up to rated speed, making sure governor takes over.
20. Check oil temperature and air-ejector cooling-water temperature.
21. Place unit on line as quickly as possible with 20% of rated load.
22. Place bleed or extraction lines in operation.

The turbogenerator should be checked frequently during the first few hours of operation. After that period a routine checking schedule is established.

When securing the plant, you once again should follow the manufacturer's recommendations. A suggested procedure would be as follows:

1. Remove extraction valves from service.
2. Reduce load to zero and quickly remove unit from service.
3. Manually trip turbine.
4. Open vacuum breaker.
5. Shut off air ejector.
6. Check to make sure auxiliary oil pump starts at correct pressure.
7. Shut off gland water and seals.
8. Shut down condensate pump.
9. Open all drains.
10. Secure condenser circulating water.
11. Keep auxiliary oil pump in operation until unit is cool.
12. Secure cooling water to oil cooler.

The main steam-stop valve to the turbogenerator can be closed, and the boiler operator can secure the boiler. The time that each operation is performed in the boiler room and engine room should be recorded in the daily log.

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Procedure: After studying the above information and the listed references, complete the following assignment.

Assignment:

1. Explain the purpose of each step in the suggested startup procedure.

2. Explain the purpose of each step in the suggested shutdown procedure.

3. Why is it important to log each operation and the time it was done?

4. Why is it important to have a definite procedure to follow when starting or stopping a generating plant?

Development of Torque **Assignment 14–A–2–M1**

Objective: Be able to determine the torque developed by a steam turbine.

Information: From your previous lessons you know that torque is defined as stress on a body which causes it – or tends to cause it – to turn. To find the amount of torque, you had to know the force acting on the element and the radius of the element.

$$\text{Torque} = \text{Force} \times \text{Radius}$$

With turbogenerators it is possible to find the torque on the shaft from the following formula:

$$\text{Horsepower} = \frac{2\pi \cdot N \cdot Tq}{33{,}000}$$

Where π = 3.1416
N = Number of revolutions per minute
Tq = Torque

If we stop for a moment to look at this formula, it may become somewhat familiar. Horsepower, we know, is:

$$HP = \frac{\text{ft. lbs./min}}{33{,}000}$$

Well, isn't $2\pi NTq$ or $2\pi N(FR)$ really foot-pounds per minute?

$2\pi NR$ = distance traveled by rim of shaft
F = force in pounds

Therefore
$2\pi NTq$ = foot pounds/min.

By transposing and solving for Tq we have:

$$HP = \frac{2\pi NTq}{33{,}000}$$

$$Tq = \frac{HP \times 33{,}000}{2\pi N}$$

$$Tq = \frac{HP \times 33{,}000}{2 \times 3.1416 \times N} = \frac{5252\ HP}{N}$$

Let us now use this formula to solve problems involving torque.

Example 1: What is the torque on a 2500 HP turbine running at 3600 RPM at full load?

$$Tq = \frac{5252 \times HP}{N} = \frac{5252 \times 2500}{3600} = 3647 \text{ ft. lbs.}$$

Example 2: Determine the torque on a 10,000 kw turbine running at 1800 RPM at full load. (1.34 HP per kw)

$$Tq = \frac{5252\ HP}{N} = \frac{5252 \times 1.34 \times 10{,}000}{1800} = 39.098 \text{ ft. lbs.}$$

Reference: *Engineering Handbook*

Procedure: After studying the information and the listed reference, answer the following questions.

Assignment:

1. What is torque on a turbine?
2. Find the torque on a steam turbine shaft which is delivering 26,000 kw at 1800 RPM.
3. Find the torque on a 3500 kw turbine shaft at 3600 RPM and running at full load.
4. A steam turbine develops 5000 shaft horsepower at 3600 RPM. How much torque is on the shaft? If the shaft is 8" in diameter, what is the force on the shaft?

Objectives: Be able to put a hydrostatic and an accumulation test on a boiler.

Be able to state the purpose of a hydrostatic and an accumulation test on a boiler.

Information: **Hydrostatic test**

It is most important that the engineering student understand the purpose of a hydrostatic test and how to get a boiler ready for it. This is a test of the strength of materials and is applied to all new boilers and also to any boiler after it has had any repair work done on its steam or water side. It is also put on a boiler that has had a low-water condition develop.

When a hydrostatic test is put on a boiler, the main steam stop-valves must be secured. The drains between the two valves must be left open. This is to prevent any water buildup in the event the valve closest to the boiler leaks. The safety valves are blanked or gagged, and the air cock is closed after the boiler is full of water at about 100°F. The water pressure is increased by the use of a hand pump to 1½ times the safety-valve setting. It is then lowered to the safety-valve setting, and the boiler is inspected for leaks or any bulging.

NOTE: When hydrostatic test and inspection are completed, be sure to remove gags or replace safety valves.

Accumulation test

An accumulation test is put on a boiler to test the relieving capacity of the safety valves. As you know, all boilers having over 500 sq. ft. of boiler heating surface must have two or more safety valves. They must be large enough, or there must be enough of them, to prevent the boiler pressure from rising over 6% above the M.A.W.P. or whatever pressure the highest safety valve is set for.

When putting an accumulation test on a boiler there should be an inspector on hand. Then you would proceed as follows: Secure all steam outlets leaving the boiler except those that might be necessary to run the boiler. Then force your fires. With all the safety valves popping, the pressure on the boiler should not have gone over the 6% figure mentioned earlier. If it has, either the safety valves are not large enough to protect the boiler or one or more is not operating.

References: *Steam Plant Operation*

A.S.M.E. Code Section 1

Procedure: After studying the above information and the listed references, complete the following.

Assignment:

1. What is a hydrostatic test?
2. What are the minimum and maximum pressures applied during the hydrostatic test?
3. a) What temperature water must be used when filling a boiler for a hydrostatic test?
   b) Why is this important?
4. a) What must be done to the safety valves during this test?
   b) Why is this necessary?
5. When would a boiler require a hydrostatic test?
6. Describe in detail how to put a hydrostatic test on a boiler.
7. What does the A.S.M.E. Code state regarding minimum safety-valve relieving capacity?
8. List 3 ways of checking safety-valve capacity.
9. Describe how to put an accumulation test on a boiler.
10. Why does the A.S.M.E. Code recommend that an accumulation test not be used on a boiler with a superheater or reheater?
11. What range of pressure-setting is allowed on boilers having more than one saturated-steam safety valve?

Objective: Be able to routinely service an auxiliary-lubrication oil pump.

Information: Normally a steam turbine will be shut down once a year for routine servicing. At that time the auxiliary-lubrication oil pump is given careful attention. The following components are serviced:

1. The steam-control valve is cleaned, diaphragm checked and replaced if bad, and the valve-stem packing is renewed. The valve is checked for correct operation.
2. The stop valves before and after the steam-control valve are checked for wear and the stems repacked.
3. The by-pass valve around the steam-control valve is cleaned and repacked.
4. Any oil leaks on the piping or flange connections are repaired. Remember, turbine oil is flammable.
5. The steam section and oil section of the pump are cleaned and checked for leaks.
6. The pump unit is now ready to be tested for correct operation.

References: *Steam Turbines and Their Lubrication* (Mobil)
Stationary Steam Turbines and Their Lubrication (Socony Vacuum)
Steam Turbine Lubrication (Vacuum Oil Co.)

Procedure: After studying the information and the listed references, complete the following.

Assignment:

1. Why is it so important to have the auxiliary oil pump functioning properly?
2. What components need checking during the yearly inspection of the auxiliary oil pump?
3. What work usually has to be done on these components?
4. How is the finished unit tested?

Objective: Be able to service a turbine governor.

Information: During the yearly service shutdown of a turbine, the governor must be checked for the following:

1. Lost motion in pins and bushings. This can cause hunting, which is a continual opening and closing of the governor. To correct this, new pins and bushings should be installed.
2. Oil leaks. These should be repaired immediately. In all probability the leak will be at a flange or joint of some type.
3. The governor valve or the admission valves have to be inspected and lapped in wherever necessary.
4. Steam-inlet strainer should be removed and cleaned.
5. On small turbines the butterfly valve should be checked for proper tripping operation. This can be set and tripped manually.
6. The throttle valve should be checked for any possible oil leaks.
7. Springs should be examined for wear or possible breaks.
8. When turbine is test-run, the overspeed trip and low-oil-pressure trip should be checked for correct operation.
9. When any painting is done around or on turbine, make sure linkage and pins have not been coated. This can cause poor or sluggish operation.

The above is just a sample. Whenever working on a steam turbine, always follow the manufacturer's recommended maintenance procedures.

References: Manufacturer's data sheet

Procedure: After studying the information and the listed reference, complete the following.

Assignment:

1. Make a list of the things that should be checked on the governor each time a turbine is down for service.
2. Explain what has to be done to each item when servicing.
3. Why is it necessary to test-run the turbine after servicing?
4. What dangers are there when painting around a governor?
5. Why is the governor such an important part of any turbine?

Objective: Be able to perform an internal inspection of a steam turbine.

Information: Every 5 years, or more frequently if requested by the insurance-company inspector, a steam turbine should be opened up for an internal inspection. The following list is a guide for such an inspection:

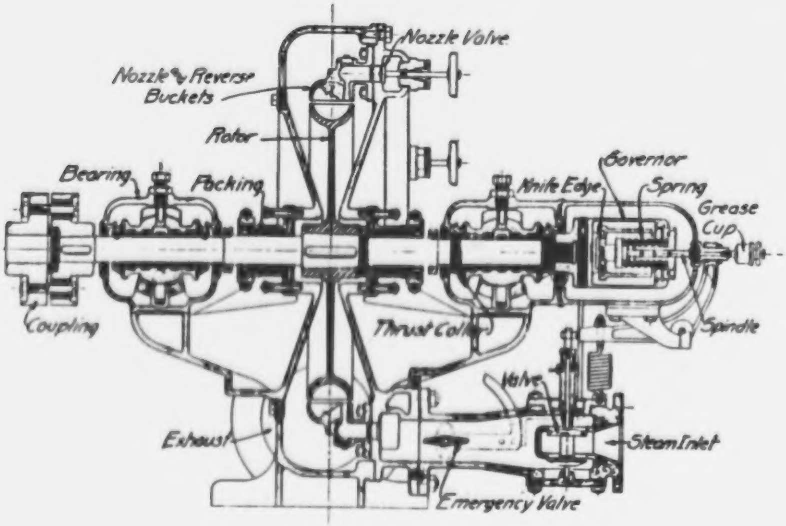
1. Check amount of shaft vibration at load and no load.
2. Check bearing-lining clearances.
3. Drain and thoroughly clean lubrication system.
4. Check nozzle and blade clearances and make sure they are within the manufacturer's tolerances.
5. Thrust bearings should be checked for clearance, wear, and any other faults.
6. Rotors should be checked for trueness and for cracks.
7. Blades should be checked for cracks and cleaned. They should also be checked for looseness in their attachment to rotor or casing and for wear.
8. Nozzles and diaphragms should be cleaned of all deposits and thoroughly inspected for wear, erosion, and water-cutting.
9. Packing rings should be removed from their cells, cleaned, and inspected.
10. Inlet-steam strainer should be inspected, and all the accumulated dirt or sediment removed.
11. Throttle and governing valves should be cleaned, and discs and seats reground if necessary.
12. Valve operating and governing mechanisms should be cleaned, and any lost motion in linkage removed by inserting new pins.
13. Oil pumps should be inspected for wear. Oil relief valves should be cleaned and reset.
14. Steam joints should be cleaned, and steam and water cuts repaired.
15. Oil lines should be cleaned and all leaks repaired.

An internal inspection normally requires a one- to two-week shutdown. All work is usually done under the supervision of the turbine manufacturer's representative.

References: Manufacturer's data sheets
Steam Plant Operation
Elementary Steam Power Engineering

Procedure: After studying the above information and the listed references, complete the following.

Assignment: Explain what would happen in each case if every item on the inspection list was ignored, and the turbine was continued in use.


Nozzle Valve
Nozzle & Reverse Buckets
Rotor
Bearing
Packing
Knife Edge
Governor
Spring
Grease Cup
Coupling
Thrust Collar
Spindle
Valve
Exhaust
Steam Inlet
Emergency Valve

IMPULSE TURBINE

Objective: Be able to perform routine service on a surface condenser.

Information: The water side of a turbine surface condenser has to be cleaned once a year. The circulating water is secured, and the water boxes on the condenser are removed. The boxes and tubes are flushed with water to remove all loose sediment and scale. The tubes are then brushed or turbined with a scraper to remove any scale adhering to the metal surfaces. When the tubes have been thoroughly cleaned, the tube sheets and water boxes are wire-brushed. New gaskets are used when replacing the water boxes. The bolts and nuts are wire-brushed and lubricated before they are assembled.

After assembling the condenser, it should be pressure-tested to determine if there are any leaks. The inlet and outlet water valves should be repacked and checked for ease of opening and closing. The atmospheric relief-valve is inspected and repaired if necessary. It is also important to check the air-ejector nozzles for possible scale buildup. Clean them and replace.

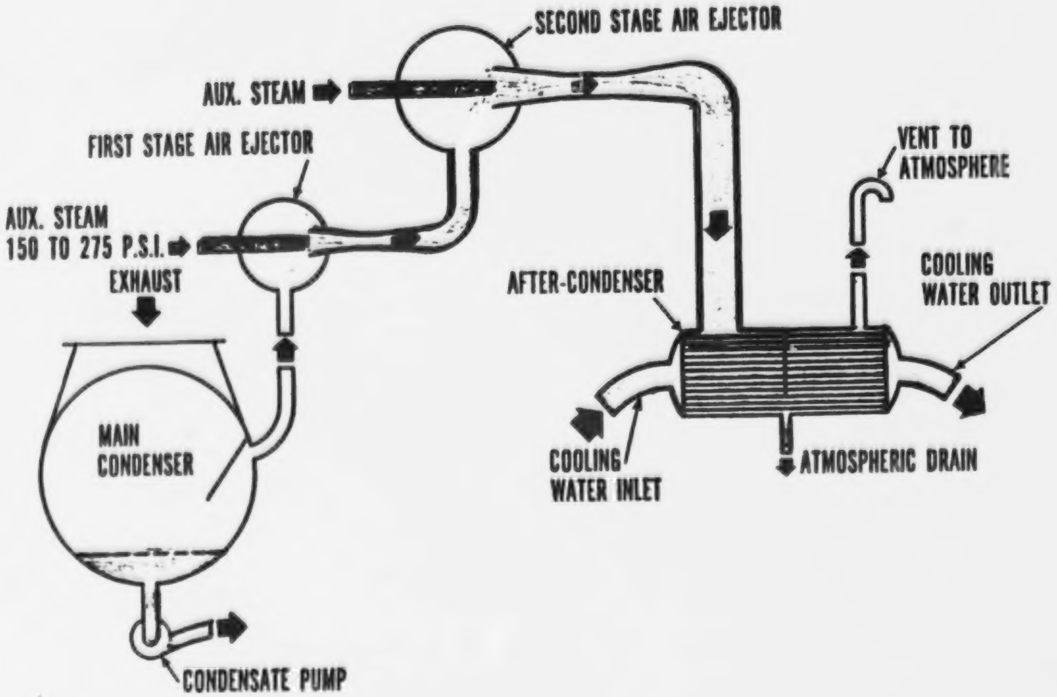
The above is only a brief outline of the procedures to follow when servicing a turbine surface condenser. You will in all cases follow the manufacturer's recommended procedures, which may even differ from plant to plant.

References: Manufacturer's data sheets
Steam Plant Operation

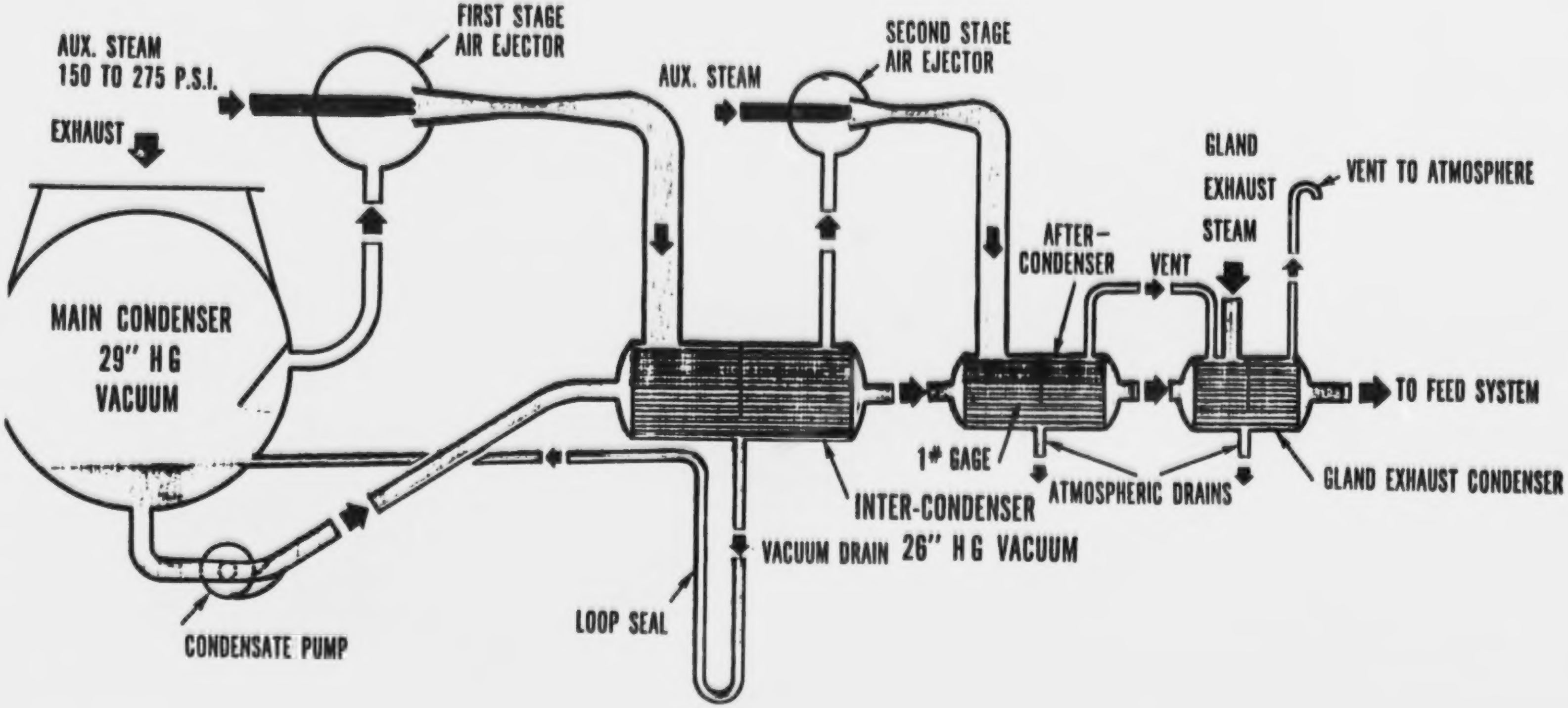
Procedure: After studying the above information and the listed references, complete the following.

Assignment:

1. Why is it necessary to clean a turbine surface condenser?
2. How do you clean a surface condenser? (From opening until closing)
3. What has to be checked on the inlet and outlet water valves?
4. What purpose does the atmospheric relief-valve serve?
5. What has to be checked on the atmospheric relief-valve?
6. What purpose does the air ejector serve?
7. What has to be cleaned on the air ejector, and why?


SECOND STAGE AIR EJECTOR
AUX. STEAM
FIRST STAGE AIR EJECTOR
AUX. STEAM
150 TO 275 P.S.I.
EXHAUST
MAIN
CONDENSER
CONDENSATE PUMP
VENT TO
ATMOSPHERE
COOLING
WATER OUTLET
AFTER-CONDENSER
COOLING
WATER INLET
ATMOSPHERIC DRAIN

TWO-STAGE AIR EJECTOR


AUX. STEAM 150 TO 275 P.S.I.
FIRST STAGE AIR EJECTOR
AUX. STEAM
SECOND STAGE AIR EJECTOR
EXHAUST
GLAND EXHAUST STEAM
VENT TO ATMOSPHERE
MAIN CONDENSER 29" HG VACUUM
AFTER-CONDENSER
VENT
TO FEED SYSTEM
1# GAGE
ATMOSPHERIC DRAINS
GLAND EXHAUST CONDENSER
INTER-CONDENSER 26" HG VACUUM
VACUUM DRAIN
LOOP SEAL
CONDENSATE PUMP

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TWO - STAGE AIR EJECTOR

15-C-1-2

Objective: Be able to perform routine service on a surface-condenser condensate pump.

Information: The condensate pump for a surface condenser is a centrifugal-type unit. It takes its suction from the hot well of the condenser and discharges the condensate into the open feed-water heater. In many installations this condensate is used to condense the vapor in the air-ejector condensers before going to the heater. Condensate is also used for sealing purposes on the low-pressure end of the turbine. Once a year the condensate pump should be serviced in the following manner:

1. All stop valves – suction, discharge, and drain – are checked for proper operation, and the stem packings renewed.
2. The pump bearings are cleaned and lubricated. If bearings are in poor condition they should be replaced.
3. The cover of the pump is lifted to check wear on rings and shaft sleeves. If worn they should be replaced.
4. Shaft-gland packing is renewed. If the pump is equipped with shaft seals, they have to be checked for wear and replaced if worn excessively.
5. The coupling between the drive and the pump has to be checked for alinement and wear.

While the pump is being serviced it is good practice to also check the recirculating line and valves. The level control on this system maintains a constant level of condensate in the hot well. Normally only stem packing is required for the valves. The gage glass on the hot well has to be cleaned and the gage-glass valves checked for leaks. Repack valves if necessary.

Each plant will have a somewhat different routine that has been established from years of experience. This unit has given you a typical schedule from a medium-sized plant.

References: *Steam Plant Operation*
Manufacturer's data sheets

Procedure: After studying the information and the listed references, complete the following.

Assignment: Your plant is shutting down for yearly servicing. Set up a routine maintenance schedule for the surface-condenser condensate pump and related equipment.

Objective: Be able to perform routine service on a surface-condenser circulating-water pump.

Information: The circulating cooling-water pump for a surface condenser is usually a centrifugal-type pump that can handle large volumes of water. It can have either an electric-motor or steam-turbine drive. The suction for the pump can come from one of several sources:

a) a cooling tower
b) a cooling pond
c) lake water
d) river water

The pump discharges through the condenser before returning the water to the tower, pond, lake, or river. Once a year the circulating-water pump should be serviced as follows:

1. Check suction and discharge stop-valves for free operation and possible need for new stem packing.
2. Clean suction screens. This may have to be done more frequently than once a year, depending upon the source of water.
3. Remove casing to flush pump and examine rings and shaft sleeves for wear. Replace if worn.
4. Check shaft packing or mechanical seals.
5. Clean and examine bearings.
6. Flush and replace lubricating oil.
7. Check coupling between drive and pump for wear and alinement.

When assembling pump, new gaskets should be used. Also the nuts and bolts for fastening cover should be cleaned and lubricated.

Reference: Manufacturer's data sheets

Procedure: After studying the above information and the listed reference, complete the following.

Assignment:

Your plant is shutting down for yearly service. Set up a routine maintenance schedule for the surface-condenser circulating-water pump and related equipment.

Pneumicator **Assignment 15–C–7**

Objectives: Be able to explain how a pneumicator functions.

Be able to perform routine service on a pneumicator.

Information: A pneumicator is used to indicate the amount of liquid in a tank. It is specifically designed and calibrated for each tank according to the shape of the tank and the liquid that is being held in it.

The pneumicator functions in the following manner. A tube is placed vertically in the tank with its open end placed close to the bottom. The top of the tube is connected to an air-pressure regulator and flow-control device. When the pressure of the column of air supports the column of liquid in the tank, the air pressure will remain constant. The line is connected also to an indicator with a gage glass. The air pressure is exerted on the liquid at the base of the glass. This causes the liquid in the glass to rise until it balances the pressure of the air. As the level of the liquid in the tank falls, less air pressure is required to maintain that height, and the liquid in the gage will fall.

Routine service on this type of pneumicator consists of keeping the indicating tube clean, adding liquid indicator when needed, and blowing the line to the tank with air to make sure it is clear.

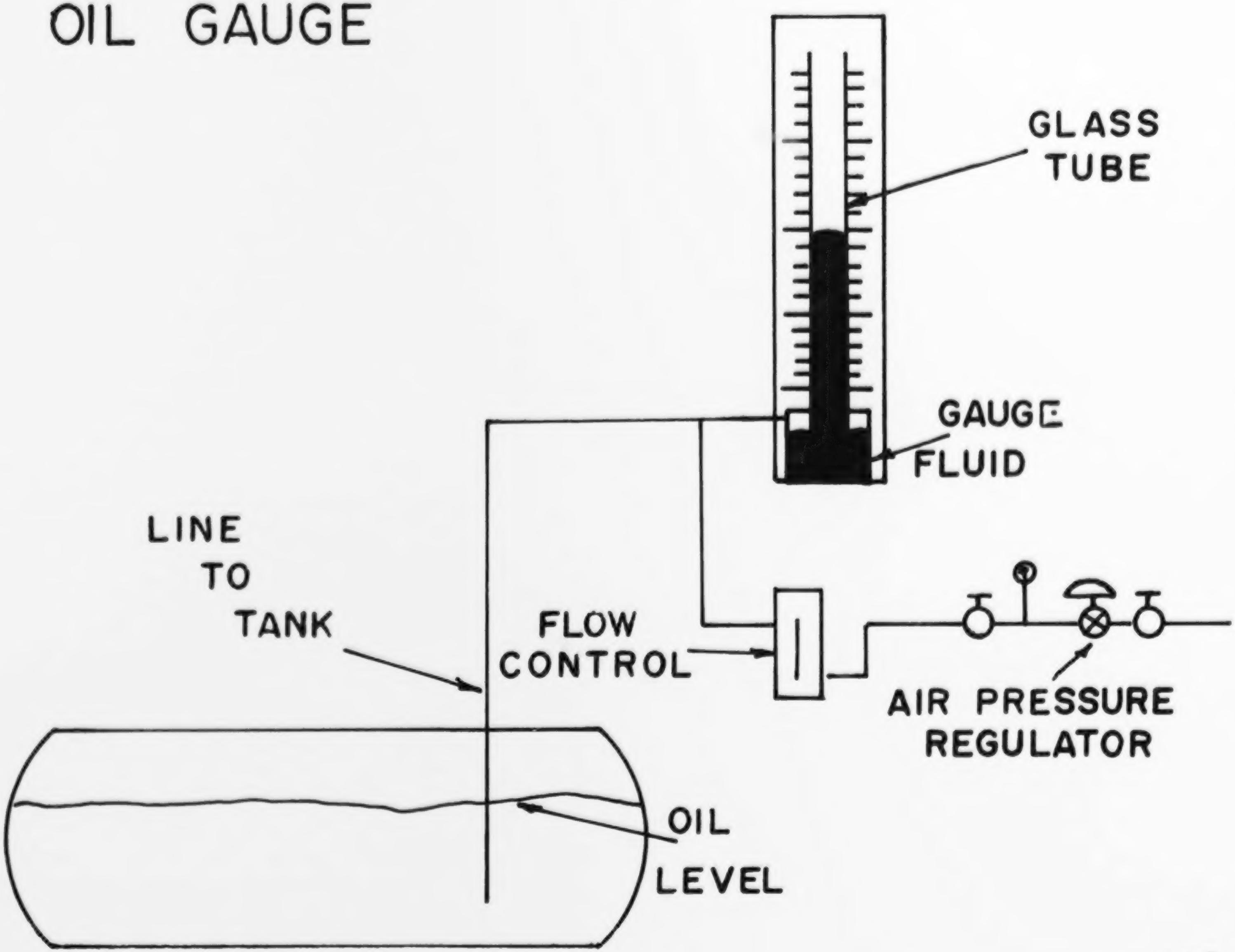
Reference: Manufacturer's data sheet

Procedure: After studying the information and the listed reference, complete the following.

Assignment:

1. What is a pneumicator?
2. How does a pneumicator function?
3. What routine service is performed on a pneumicator?
4. Can any fluid be used in a pneumicator? Explain.
5. How reliable is this type of liquid-level indicator?

OIL GAUGE


GLASS
TUBE
GAUGE
FLUID
LINE
TO
TANK
FLOW
CONTROL
AIR PRESSURE
REGULATOR
OIL
LEVEL

Objectives: Be able to fill out an application for a Boiler Operator's exam.

Be able to pass sample Black Seal High-Pressure Boiler Operator's License exams.

Information: In order to sit for a Boiler Operator's License, you must first fill out an application and have it approved by the Mechanical Inspection Bureau. You will need a letter from your Guidance Department showing number of hours spent in shop and related science. You will need to have your application signed by your engineering instructors (Blue Seal or better). If you have only one such instructor, it should be OK provided you have the letter from Guidance.

The application must be notarized, and a $10.00 check made out to the Mechanical Inspection Bureau must accompany the application and letter.

Your engineering instructor will instruct you in how to fill out the application.

References: State application
3 years of notes and related science manuals

Procedure: After studying the information and listed references, complete the following.

Assignment:

1. With the help of an instructor, fill out the state application.

2. Get the necessary letters from Guidance Department.

3. Take sample exams.